

## **General Disclaimer**

### **One or more of the Following Statements may affect this Document**

- This document has been reproduced from the best copy furnished by the organizational source. It is being released in the interest of making available as much information as possible.
- This document may contain data, which exceeds the sheet parameters. It was furnished in this condition by the organizational source and is the best copy available.
- This document may contain tone-on-tone or color graphs, charts and/or pictures, which have been reproduced in black and white.
- This document is paginated as submitted by the original source.
- Portions of this document are not fully legible due to the historical nature of some of the material. However, it is the best reproduction available from the original submission.

(NASA-CR-170341) SATELLITE-TRACKING AND  
EARTH DYNAMICS RESEARCH PROGRAMS Semiannual  
Progress Report, 1 Jul. - 31 Dec. 1982  
(Smithsonian Astrophysical Observatory)  
77 p HC A05/MF A01

N83-24920

Unclas  
03663

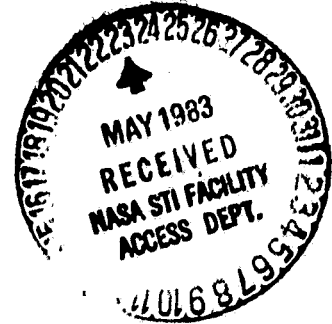
CSCI 08G G3/42

## SATELLITE-TRACKING AND EARTH DYNAMICS

### RESEARCH PROGRAMS

Grant Number NGR 09-015-002

Semiannual Progress Report No. 47



1 July to 31 December 1982

Prepared for

National Aeronautics and Space Administration  
Washington, D.C. 20546

May 1983

Smithsonian Institution  
Astrophysical Observatory  
Cambridge, Massachusetts 02138

The Smithsonian Astrophysical Observatory  
is a member of the  
Harvard-Smithsonian Center for Astrophysics

The NASA Technical Officer for this grant is Mr. David L. Townley, Code  
TN-1, Network Operations, Office of Space Tracking and Data Systems,  
NASA Headquarters, Washington, D.C. 20546.

SATELLITE-TRACKING AND EARTH DYNAMICS

RESEARCH PROGRAMS

Grant Number NGR 09-015-002

Semiannual Progress Report No. 47

1 July to 31 December 1982

Prepared for

National Aeronautics and Space Administration  
Washington, D.C. 20546

May 1983

Smithsonian Institution  
Astrophysical Observatory  
Cambridge, Massachusetts 02138

The Smithsonian Astrophysical Observatory is a member of the Harvard-Smithsonian Center for Astrophysics
--

The NASA Technical Officer for this grant is Mr. David L. Townley, Code TN-1, Network Operations, Office of Space Tracking and Data Systems, NASA Headquarters, Washington, D.C. 20546.

## TABLE OF CONTENTS

	Page
1 INTRODUCTION AND SUMMARY.....	1
2 OPERATING STATUS.....	4
3 LASER OPERATIONS AT COOPERATING AGENCIES.....	8
4 SATELLITE OBSERVING CAMPAIGNS.....	9
5 OPERATIONS AND MAINTENANCE ENGINEERING.....	10
5.1 Laser and Photoreceiver.....	10
5.2 Data Systems and Pulse Processor.....	11
5.3 Minicomputers.....	13
5.4 Timekeeping.....	14
5.5 Documentation.....	17
6 COMMUNICATIONS.....	19
7 DATA SERVICES AND PROGRAMMING.....	22
7.1 Data Services.....	22
7.2 Programming Support.....	25
7.3 Routine Programming.....	26
7.4 Laser Control and Processing Software.....	28
8 STATUS OF LASER UPGRADING.....	32
9 DATA QUALITY .....	39
9.1 Range Accuracy.....	39
9.2 System Noise.....	51
10 RELOCATION OF SAO 1 TO MATERA, ITALY.....	57
11 STATUS OF SAO 3 AND 4.....	61
12 PERSONNEL.....	62
12.1 Travel.....	62
12.2 Visitors.....	63
12.3 Personnel.....	63
REFERENCES.....	64
APPENDIX	

**SATELLITE TRACKING RESEARCH PROGRAM IN  
SOLID-EARTH GEOPHYSICS**

**Semiannual Progress Report No. 47**

**1. INTRODUCTION AND SUMMARY**

This report describes the activities carried out by the Smithsonian Astrophysical Observatory (SAO) for the National Aeronautics and Space Administration (NASA) under Grant NGR 09-015-002 during the period 1 July to 31 December 1982. Work on geodesy, geophysics and the upper atmosphere are currently funded separately from this grant, although that research is still maintained as part of a total integrated program at the Observatory. Reports related to this are included in Appendix 1.

The SAO laser in Arequipa was in routine operation during the reporting period. The laser, which was upgraded during the previous reporting period, continues to operate at the specified level. Range noise is typically 12-18 cm on Lageos and 6-15 cm on the low orbiting satellites. Accuracy is estimated at 3-5 cm based on detailed ground based measurements.

The Arequipa station obtained a total of 43,697 quick-look range observations on 912 passes in the six months. In addition, routine participation by cooperating networks contributed greatly to the success of ongoing tracking campaigns. Data were acquired from Metsahovi, San Fernando, Helwan, Kootwijk, Wettzell, Grasse, Simosato and Graz.

During the reporting period work progressed on the relocation of SAO 1 to Matera, Italy. The buildings are under construction and the upgraded laser equipment is in shipment from SAO. Under the current plan, the station will be operational by July 1983.

Arequipa and the cooperating stations continued to track LAGEOS at highest priority for polar motion and earth rotation studies, and for other geophysical investigations, including crustal dynamics, earth and ocean tides, and the general development of precision orbit determination. At lower priority, BE-C and Starlette were tracked for refined determinations of station coordinates and the earth's gravity field and for studies of solid earth dynamics.

During the previous reporting period, the construction of all production hardware for the upgrading of SAO 1 and 3 were completed. Testing is currently underway. Work continues on the modifications to manuals and documentation to reflect the upgrading changes to hardware, software and operations.

Cesium standards and Omega receivers provided on long-term loan by the U.S. Coast Guard continue to function well at Arequipa. With these and other timekeeping aids, the station has been able to maintain a timing accuracy of better than plus or minus 6 microseconds.

The communications links with Arequipa, Peru have continued to operate satisfactorily.

Data Services has provided final data to the National Space Science Data Center for the period through November 1982. Final data are now being furnished on a routine basis 60 days after the end of the acquisition month. Most of the software activity was focussed on the refinement of the field software for the greater operator effectiveness and improve field diagnostics.

The minicomputer to VAX link in Cambridge continues to function well. The minicomputers are now routinely used as interactive terminals and as remote data-entry devices. They provide Data Services and other support groups with a remote-batch capability and facilitate the processing of quick-look data.

## 2. OPERATING STATUS

During this reporting period, the laser in Arequipa tracked 912 satellite passes, of which 204 were Lageos. Lageos passes averaged 260 points with some yielding as high as 400-600 points. During a "good" pass, the rate of return was typically 20%-50% depending upon sky conditions and satellite altitude. In many of the passes the satellite was acquired at altitudes as low as 10 degrees, and tracked through zenith back down to 10 degrees.

For the lower orbiting satellites, (Starlette and BE-C), data yield per pass varied from 50-100 points with occasional yields as high as 150 points. Here the rate of return was in the range of 20%-80% with intervals as high as 100%. The low altitude acquisition experience with these satellites was similar to that of Lageos.



TABLE 1.

Quick-look passes and points, 1 July through 31 December 1982

Station	July		August		September		October		November		December		Total	
	Passes	Points	Passes	Points	Passes	Points	Passes	Points	Passes	Points	Passes	Points	Passes	Points
Arequipa	217	12269	186	9452	134	6404	144	5835	66	2221	165	7516	912	43697
Metsahovi			9	254	11	319	4	140	8	195	2	62	34	970
San Fernando	23	973	2	43	15	529	6	314	18	933	12	1073	76	3865
Helwan			9	440									9	440
Kootwijk					19	358	8	230	14	265	8	216	49	1069
Wettzell	18	598	31	967	33	1104	17	568	12	413			111	3650
Grasse	4	159					21	978	28	889			53	2026
Simosato	3	31	7	144	2	23	21	363	13	193	19	479	65	1233
Graz							1	17	2	35			3	52
TOTAL	265	14030	244	11300	214	8737	222	8445	161	5144	206	9346	1312	57002

Satellite	July		August		September		October		November		December		Total	
	Passes	Points	Passes	Points	Passes	Points	Passes	Points	Passes	Points	Passes	Points	Passes	Points
BE-C	109	4539	77	2857	61	2150	78	2542	34	1298	78	3432	437	16818
Starlette	77	3462	87	3392	77	2719	69	2436	56	1496	72	2498	438	16003
LAGEOS	79	6029	80	5051	76	3868	75	3467	71	2350	56	3416	437	24181
TOTAL	265	14030	244	11300	214	8737	222	8445	161	5144	206	9346	1312	57002

ORIGINAL PAGE 18  
OF POOR QUALITY

Table 2.

Final Data Statistics - Arequipa Peru

July-December 1982 Passes/Points

Satellite	July		August		September		October		November		December		Total	
	Passes	Points	Passes	Points	Passes	Points	Passes	Points	Passes	Points	Passes	Points	Passes	Points
BE-C	83	6090	69	5309	46	2511	58	4126	11	392	61	4272	328	22700
Starlette	76	7537	70	6434	55	4386	55	4025	35	1457	59	4643	350	28482
LAGEOS	57	17407	45	10750	30	5988	25	3829	15	934	32	7463	204	46371
Arequipa Peru														
TOTAL	216	31034	184	22493	131	12885	138	11980	61	2783	152	16378	882	97553

ORIGINAL PAGE IS  
OF POOR QUALITY

Table 3.

Laser operations summary, 1 January through 30 June 1982.

Station	Passes scheduled	Passes supported	Data obtained*	Passes cancelled owing to weather** system down other
Arequipa	1397 (100%)	1159 (83%)	903 (76%)	204 (15%) 29 (2%) 3 (0%)

\* Number of passes and percent of total scheduled minus passes canceled because of weather.

\*\* Not included are passes attempted but unsuccessful because of poor weather.

### 3. LASER OPERATIONS AT COOPERATING AGENCIES

Cooperating foreign stations actively participating and providing quick-look data during the reporting period were:

San Fernando, Spain

Simosato, Japan

Kootwijk, Netherlands

Metsahovi, Finland

Wettzell, Federal Republic Of Germany

Some data was also received from Grasse, France; Graz, Austria; and Helwan, Egypt. The station in Helwan provided some data in August but has since closed down operations. The station in Graz, Austria, has been operational for only a short time and provided data on a regular basis in October and November. Data received from the new Sylvania system purchased and operated by the Japanese Hydrographic Service has been of good quality and during the last three months has been received on a very regular basis.

The cooperating foreign stations have been particularly helpful in maintaining orbits on the two low satellites (BE-3 and Starlette) as the GSFC sites have not scheduled observations of these satellites for long periods of time.

The period of bad weather in Peru normally begins in late October and worsens thru November and December. This year after a brief period of clouds in early November, the weather cleared and remained remarkably good through the end of December.

#### 4. SATELLITE OBSERVING CAMPAIGNS

The laser tracking network continued its program of data acquisition, with particular emphasis on follow-up support for the preliminary MERIT Campaign. In addition, satellite observations were made to:

A. Support the scientific and orbital maintenance requirements for LAGEOS and the Crustal Dynamics Program.

B. Support the study of earth body and ocean tides, seasonal and other variations in the earth's gravity field, and the investigation of polar motion.

C. Provide data for improving the accuracy of station coordinates and the gravity-field model, which are necessary for LAGEOS and other geophysics programs.

D. Support the tracking campaign for Starlette in conjunction with CNES.

With the success of the preliminary MERIT Campaign in 1980, work continues on a routine but informal interim basis to keep continuous tracking coverage on LAGEOS and Starlette and to continue the routine calculation of pole position from all available quick-look data. This is particularly important for all investigations involving long period effects such as the annual and Chandler effects.

## 5. OPERATIONS AND MAINTENANCE ENGINEERING

The Engineering Group of the Experimental Geophysics Department provides the daily hardware and systems support necessary to maintain routine network operations. It is also responsible for the system modifications and improvements required for new programs.

### 5.1 Laser and Photoreceiver

Thin film polarizers purchased in the past from OCLI and Trans World Optics exhibited early coating failure. Two polarizers from CVI were tested at SAO-2 and found acceptable. Twelve more polarizers were ordered from CVI.

Daylight ranging was tried on Lageos with some success, particularly during twilight hours. Ongoing systematic tests with narrow range gate and improved prediction combinations are now being tried to improve the success ratio.

Since the last upgrade, the Arequipa system (SAO-2) has performed without major hardware problems. Extreme line power brownouts in the evening hours by the local power company has at times limited the system repetition rate to 24 ppm versus the normal 30 ppm for Lageos tracking.

The new, high repetition rates have also shown that the flashlamp cooling loop is somewhat undersized and additionally, thermal expansion caused water leaks to develop in the lamp cavities. To eliminate those problems, two cooling units formerly used at Mt. Hopkins were modified for 50 Hz operation. One unit was sent to SAO-2 and the other was included in

the shipment to Matera, Italy.

In addition, refurbished lamp cavities and associated laser rod holders were sent to the two sites. The Peru items are in the country and await custom clearance.

SAO-2 also experienced failures of the dry air pump for the laser and the PMT shutter in the Photoreceiver. Local rewinding of the dry air motor was unsuccessful and a backup system was used while a replacement was sent to them. The PMT shutter was replaced with an on-site spare.

## 5.2 Data System and Pulse Processor

During the past six months, work has continued on improving and fine tuning the electronics which were upgraded for laser operation at 30 ppm with a 3 ns pulse.

Receiving instabilities in the Peru Nanofast counter prompted a series of tests on the three counters from Australia, Brazil and Mt. Hopkins now at headquarters. The tests checked for unique signatures and characteristics so that a replacement could be chosen from the three counters and sent to Peru. This would then enable the station personnel to investigate more fully and resolve the problem with their primary counter. Test results showed that the systematic errors for each counter were different and was attributed to small differences in circuit paths and cross coupling of signals within the counter itself. An overall measuring accuracy for the three counters of 0.3 nS peak to peak ( $\pm 0.15$  nS) was

measured which compares with the manufacturers specification of 0.2 nS peak to peak ( $\pm 0.1$  nS). The bad counter in Peru was subsequently repaired and returned to service. A long term electronic system stability test showed a peak to peak variation of 60 picoseconds.

Some problems were experienced in Peru with instability in the range delay and window generated by the Range Gate generator, particularly at the narrow window of 100-200 ns. Tests at SAO showed that circuit delay conflicts were occurring in both the Range Gate Generator and Laser Clock and were due to the variations in delay between individual IC devices causing at times a marginal timing condition. A faster logic device family was used which resolved the problem. Replacement circuit cards were made up, tested and sent to Peru for inclusion in their Range Gate Generator and Laser Clock. They have been installed and are performing well.

With upgrading and shake down tests completed in Peru, the station has returned to routine operation, no other major hardware problems have occurred.

Upgrading of the Brazil station equipment and modification for operation at 50 Hz in readiness for Matera, Italy was completed. Most of the electronic components were packed in a sea freight shipment which will leave for Italy in early January 1983. The remainder of the electronics was retained at headquarters and will be sent in a future air freight shipment.



The majority of equipment has been packed in Orroral Valley in readiness for shipment to the US early next year.

### 5.3 Minicomputers

In preparation for the upcoming Italy laser site installation, two Nova 1200 computer systems, peripherals, and spare peripherals were overhauled, assembled and tested in Cambridge. These two systems will be shipped to the new Italy site.

Several sets of Linc tape drives in use in Cambridge were also overhauled, though four sets out of twelve still remain to be overhauled. The twelve total sets include the three sets for Italy.

The NASCOM baudot teletype communications facilities were upgraded to ASCII direct-computer communications through the installation of the Bell Comm-Star II equipment. We now have a NASCOM communications system integrated into an overall observatory communications system through direct VAX computer, TWX, telex and NASCOM serial data interconnections.

During this six month period only two minor hardware failures occurred on our Cambridge minicomputer systems. These hardware problems were immediately corrected and incurred no down time.

The 9 track magnetic tape drive Nova 1200 software driver project was deferred until early in 1983 due to manpower shortage. Completion of this software project is anticipated in February of 1983.

#### 5.4 Timekeeping

During the reporting period, timekeeping systems for the Peru tracking station have maintained epoch time traceable to UTC (US Naval Observatory reference) with an accuracy of at least plus and minus 7 microseconds. The Egypt tracking operation has not provided any timing reports during the period. However, the site is capable of maintaining plus and minus 50 microseconds with its LORAN reference. Each of the NASA supported SAO tracking sites is equipped with a broad-based timing system comprised of dual parallel timing channels. Cesium oscillators, backed up by rubidium oscillators, offer a stable time base for each channel. Redundant time accumulators guard against time discontinuities, and redundant VLF/OMEGA receivers provide a reliable backup and frequency reference for the system. Portable clock comparisons are required to provide the necessary epoch reference checks until a satellite-based time transfer system can be implemented.

No portable clock trips were needed during the time period. One will be required during the next half year.

OMEGA time data is being collected at SAO headquarters and Peru for the US Coast Guard for input into their global OMEGA transmission model. OMEGA is used for a primary frequency reference for the Peru site.

Satellite timekeeping systems were surveyed for improving SAO timekeeping accuracies. Both leading satellite-based timing systems have major drawbacks for SAO. Though the TRANSIT/NOVA system is affordable, accuracies are still not realized to the potential of the system and are

still not able to provide better accuracies than being maintained by present SAO systems. The GPS system, on the other hand, provide fine accuracies at a very steep purchase price. Though GPS receiver prices are expected to fall in the next three years after their development costs are recovered, it is not clear whether the GPS transmissions now accessed by civilian users will be degraded.

Preparations are underway to ready timing equipment to be shipped to a new Italian satellite tracking installation in the middle of 1983. A rubidium oscillator has been repaired for use in that system.

Note Table 4, titled, "SAO Network Timekeeping Status for the period May, 1982 thru Jan, 1983".

ORIGINAL PAGE IS  
OF POOR QUALITY

Table 4

SAO NETWORK TIMEKEEPING STATUS for May 1982 to Jan 1 1983

Definitions:

(STAT - UTC) = epoch range of SAO field station main clock;  
a positive quantity means station clock ahead of UTC  
as maintained by the US Naval observatory (USNO)

REDUCTION UNCERTAINTY = estimated absolute error of reduced station  
time during the period specified. Future clock comparisons  
may lower this uncertainty value.

EPOCH SET UNCERTAINTY = estimated epoch time transfer accuracy

LAST COMPARISON = the last portable clock comparison on site  
Cs refers to cesium portable and Xtal to crystal  
portable

STATION	REDUCTION PERIOD from thru	(STAT - UTC) RANGE microseconds	REDUCTION UNCERTAINTY <+/-microseconds	EPOCH SET UNCERTAINTY <+/-microseconds	LAST COMPARISON by when	
EGYPT	may 1 82		50		Czech/Cs 81	no data received
PERU	may 1 82 jun10 82	22 to 31	5	2	Bend/Cs	aug28 81
	jun10 82 sep 2 82	7 to 20	4 to 5	2		
	sep 2 82 jan 1 83	0 to 21	4 to 7	2		
	except dec 6 82 dec 6 82	80031	6	2		
	except dec13 82 dec13 82	23 to 29	6 to 8	2		

## 5.5 Documentation

During this past year a significant portion of the system hardware was upgraded, and the corresponding documentation was also revised. A preliminary release of documentation updates was made in both April and November of 1982. However, the bulk of the material will be released in February of 1983.

The updating process involved all Smithsonian hardware and operational manuals, and some manufacturers manuals. The nature of the work involved all aspects of manual content, i.e., drawings, wire and parts lists, and theory. The revisions to some manuals were so extensive that they will be completely reissued. Additionally, three new manuals were written and will be added to the series in this major release.

Following is a list of all manuals involved in this updating project:  
SAO Manuals

1. Laser Data System Manual Series

Volume-1	Clock, RGG, Amplifier Monitor (1)
Volume-2	Clock, RGG, P.C. Board Data (1)
Volume-3	SAO Chassis Drawings
Volume-4	Tape Control Unit (1)
Volume-5	Laser Control Unit (2, 3)
Volume-6	Analog Detector Unit (3)

2. Modified Laser Data System Manual Series

Volume-1	System Theory (4)
Volume-2	System Hardware (1)
Volume-3	System Operations (4)

3. Laser Ranging System Maintenance and Calibration Manual (3)

4. Pulse Processor System Photographs

5. M & W System Cooling Unit (3)

- (1) Updates issued in April & November of 1982, and also February of 1983.
- (2) Preliminary copy issued in April 1982.
- (3) New manual issued in 1983.
- (4) Complete reissue due to extensive revisions, 1983.

Manufacturers Manuals

Nanofast Counter Manual  
Ortec 934 Discriminator Manual  
Ortec 402D (Nim-Bin) Power Supply Manual  
LeCroy 821 Discriminator Manual  
LeCroy WD2000 Digitizer Power Supplies

- a) R.O. Model 105
- b) R.O. Model 107

## 6. COMMUNICATIONS

The past reporting period was one of the most active times for the communications group as far as hardware is concerned. The facilities had been moved to smaller quarters during the last reporting period and a program was begun to upgrade the equipment to be more efficient, more effective in handling data, and to overcome the severe noise problem in the new quarters.

At the start of the reporting period all traffic was handled in Baudot (5 level) paper tape by electro-mechanical equipment. At the end of the reporting period all systems had been tested for complete conversion to 8 level non-mechanical storage medium, and only the radio link was not operational in this new mode.

The NASCOM link was upgraded from two incoming and one outgoing 5 level 110 baud lines to one incoming and one outgoing 8 level (ASCII) 300 baud lines. A teletype model 40 printer, keyboard, and screen along with two Comm-stor disk drives were installed during the reporting period. Some problems were encountered with the new equipment because of unfamiliarity by the local telephone company, but with the help of NASA communications and C&P telephone company personnel the system bugs were worked out and by the end of the reporting period the system was fully operational. The system provides automatic recording of data on disk and permits switching of all messages and data to the VAX computer for processing and/or distribution.

Traffic is received at the Communications group from some of the cooperating overseas stations via international Telex. A new piece of hardware was obtained at no cost to NASA which handles Telex, TWX, and DDD (dial up computer line). The system automatically answers and sends data on Telex and TWX with automatic 5 to 8 level conversion and 300 baud to 110 or 75 baud switching and buffering. The system also allows for switching data from built in semiconductor memory to the VAX computer. This new equipment has also been tested with the G.E. Mark III system and was successful in switching orbits from the VAX computer to the Mark III computer. This system could be used to send orbits to the cooperating European Laser stations and to receive their quick-look data at a substantial savings in cost over commercial Telex.

The hardware and software upgrades to the radio TTY link, used to communicate with the laser station in Peru, were completed and tested during the reporting period. This modification will allow conversion of the radio TTY link from 5 level (Baudot) to 8 level (ASCII), and to convert from ancient model 28 TTY's to using the Data General Nova 1200 computers to pass and record data. Hardware and software has been shipped to Peru and the system is expected to be operational early next year.

The Radio link with Peru was showing its age during the last reporting period. Although no radio operations downtime was incurred, both systems at Cambridge had problems which required servicing. Many of the components within the two transmitters are marginal due to aging and a program was initiated to test and replace these items.



Traffic was handled regularly and routinely to the laser station in Peru during the reporting period via Radio. Data from cooperating laser stations in Japan, Holland, Germany, and Switzerland were handled via Telex. Observations were routinely received from all other sites via the NASCOM line.

## 7. DATA SERVICES AND PROGRAMMING

The Data Services Group performs the central data processing necessary for the efficient operation of the SAO field stations. This group screens and validates all incoming data, generates orbital elements for all satellites being tracked by the SAO laser network and cooperating stations, supplies orbital elements to SAO stations and other agencies, and furnishes SAO laser data to the Crustal Dynamics Project at GSFC.

### 7.1 Data Services

The two major activities of Data Services are the quick-look processing cycle and final data processing. The quick-look activity cycles on a weekly schedule, in which the SAO and cooperating foreign field stations send small subsets of their acquired data through communications channels to Cambridge. These data then form the basis for generating updated orbital elements, which are communicated back to the field stations, where they are used to compute the look angles necessary for laser satellite ranging.

The full data sets on Linc magnetic tape are mailed from the SAO laser stations to Cambridge and sent through the final data-processing chain. This sequence of processes consists of an engineering filter to assess data quality, followed by a noise filter, a time correction program and a formatter.

The quick-look functions of the Data Services operation have evolved into a stable, reliable, and smoothly running procedure. Acquisition orbits were computed and transmitted each week virtually without incident. The quality of these orbits is very high; ephemerides are now routinely computed to the sub-10-meter level and, in the case of LAGEOS, to the 2-meter level.

In the second half of CY 1982, the Data Services group processed 57,002 laser quick-look data points and handled 1,312 passes of Starlette, BE-C, and LAGEOS from the SAO and cooperating stations (see Tables 1, 2 and 3).

During the reporting period, the Data Services group, using LAGEOS data from the SAO and NASA laser networks as well as from certain cooperating foreign organizations, provided 5 day mean pole positions as a by-product of the routine orbital determination and data assessment activity. The pole positions are transmitted weekly to the B.I.H. in Paris as a rapid service to the world scientific community.

In the second half of CY 1982, the Data Services group processed and sent 97,553 points in 882 passes of data to the Crustal Dynamics Project at GSFC. The Data Services group has maintained 60-day turnover on final data submission. Final data from the SAO laser network from October 1982 were transmitted to NASA by year's end.

SAO compiles and publishes the quick-look data catalog for satellites tracked by the laser systems. The tabulation includes all quick-look data submitted. This catalog also now contains the 5 day mean positions of the earth's pole which is obtained as a by-product of the data validation process. See Figure 1 for the SAO determined polar motion for 1982.

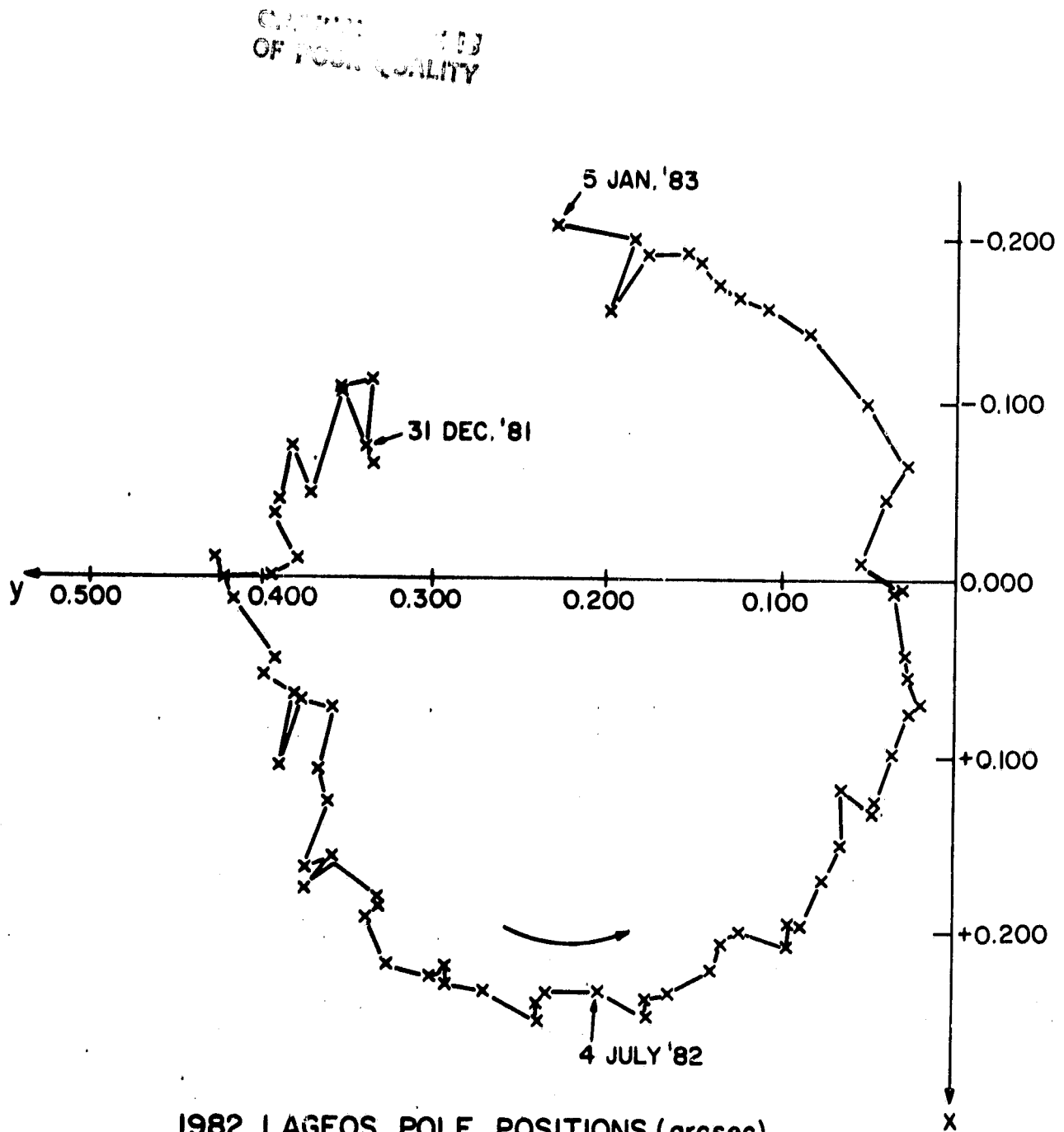
The quick-look catalog for CY 1982 is being prepared for distribution.

Upgrading of the final data processing system continues with near completion of 9-track tape capability for the Nova 1200 to replace the current 7-track tape capability.

## 7.2 Programming Support

SAO maintains a small staff of computer programmers who support the operation of its tracking program. In addition to routine maintenance and upgrading of the minicomputer and production processing programs, the Programming Group develops software to meet new needs and supports the Data Services Group in routine processing as necessary. The Programming Group analyzes test data for laser-system maintenance and for planning laser-system modifications to improve performance.

Figure 1



1982 LAGEOS POLE POSITIONS (arcsec)  
DERIVED FROM QUICK LOOK DATA  
FIVE DAY INTERVALS

### 7.3 Routine Programming

The minicomputer 9-track tape driver WRITE package was completed in July, and partially tested in August. When the READ package is complete, the 7-track tape drive can be phased out and the full-rate data processing chain simplified, from receipt of Linc tapes from field sites to submission of final data to NASA.

In July, testing of the field prediction software (FLPPS) after adding a 205 nsec range adjustment (to compensate for hardware-induced signal delay) revealed a bug in the evasion strategy module which was repaired. Peru reported an error in August, which was exhaustively tested, but could not be reproduced at headquarters. The problem has not recurred. In response to queries from Wettzell, who use the orbital elements generated by SAO for acquisition, testing for compatibility between FLPPS and the orbit determination software (GRIPE) was undertaken to ensure total system integrity. Plans were made to assist the Germans in upgrading their software, and test data were compiled and furnished in October. As a by-product of this effort, it was decided to add a few small terms to the luni-solar perturbation routines. The effect is not large, but represents a slight improvement.

In this reporting period there was a general upgrading of communications procedures. One program affected was the QUICK2 quick-look teletype message generation program run at the field sites on the DG NOVA 1200. The change made was to add the option of ASCII Linc tape file generation instead of the BAUDOT punched paper tape output. This permitted file transfer from the computer to the radio by means of cassette tape

(superSeded later in the year by hardware modifications to the computer). The QUICK2 program also permits field analysis of data, and improvements were made in this area also. A version of this program was prepared which uses a convolution technique for data screening, as a practical alternative to the polynomial fitting algorithms used in the headquarters processing routines on the DEC VAX. Another benefit is that longer passes can be analysed than before, with core storage of data being increased from 225 to 387 points.

Another communications program was completed which enables computer-to-computer communication and file transfer between field site and headquarters via the HF radio link. This program is the key to permitting retiring the paper tape hardware at field sites, thereby speeding the transmission of quick-look data from Peru to Cambridge and orbital elements to the field sites. It was fielded successfully in December, 1982.

There was another communications capability added in this reporting period. This was the communications center system enabling file transfer with the GE Mark III system. We use this system to report Earth pole positions derived from Lageos quick-look data to the BIH and the USNO.

In July, two small routines were developed to facilitate display of data quality: a package to produce histograms of final data residuals and a plot routine to display calibration stability values.

Quick look laser data screening capability was enhanced by an improvement to the systematic bias data analysis program to allow for differing data characteristics among stations.

A comparison of the station coordinate systems used at SAO and at the University of Texas revealed that there is no significant difference between the two systems at the two-meter level.

Programming and processing were provided to assist Dr. S. Zerbini, visiting scientist from the University of Bologna, Italy, in preparing simulated data for a study of an Italian Lageos type satellite project.

In addition, some effort was devoted to word-processing software for use by the administrative staff.

#### 7.4 Laser Control and Processing Software

The goal of speeding up the Laser Control and Processing program ("Direct Connect") to operate with a 30 ppm lasing rate was accomplished during the last semi-annual period. Two techniques were used:

- The efficiency of key routines was improved by modifying the assembly code produced by the Fortran compiler; this reduced computation time for these routines by factors of five to ten.
- Based on the fact that not every lasing produces a return, Direct Connect was modified to ignore input from the intercoupler if the internal data buffer is full. This allows operation at lasing rates in excess of the throughput rate. Normally there are enough lasing cycles without returns that all data are processed. The program copes with the very occasional rapid burst of data by losing an insignificantly small number of points.



These modifications resulted in successful operation in Peru at 30 ppm, with minimal data loss. Thus, it was decided not to significantly restructure the output format (both raw and reduced data tapes are retained), and during the current semi-annual period effort was turned to operational improvements in Direct Connect.

One major set of modifications involved processing control in Direct Connect. First, the dependency of cycling between processing subsections (e.g. from pre-pass calibration to satellite lasing) upon the contents of the digitized pulse signal was completely removed. Previously, the program had in some cases used, for instance, the peak signal to discriminate between subsections; this is no longer desirable since the digitized signal is not now used for range determination and is only being retained in case it may assist any trouble-shooting necessary. Second, a facility was introduced for the operator, using a console command, to force cycling from one subsection to the next: This is intended to allow the operator to obtain summaries for the pre-calibration without waiting for the first satellite return, but it simultaneously avoids doing lengthy summary computations while in the time-critical data-taking phase. Finally, modifications were made to operate in the case of a complete digitizer failure. The operator sets the intercoupler to "First Line Data" mode (in which it does not pass on the digitized pulse), enters a console command to Direct Connect, and proceeds normally. Direct Connect then creates simulated digitizer data (a null pulse) on the raw and reduced data files so that the downstream software may operate with minimal modifications.

The other operational modification is the facility to change the range gate window sent to the mount controller ("tape control unit") and to adjust the predicted range in real time. Previously, these quantities were created by FLPPS in the predictions line file, which was then read by Direct Connect and passed to the mount with no modification. Now, the operator will be able to change the window at the beginning of or during the pass; the predicted range is automatically adjusted to center the return pulse in the window. An arbitrary system calibration offset is also applied to the predicted range; the operator may change this offset as required to center the return. These modifications have been coded but they await operational testing.

A number of minor changes were also made to Direct Connect: The console-printed summary display was cleaned up, removing items either no longer applicable due to program changes or of little use to the operators. The console screen display was modified for greater clarity. An average zeroset area is computed and subtracted from subsequent pulse areas: In the pre- and post-cal, the computation of a mean and standard deviation for the pulse area is restored. This calculation had been removed from the summary calculations to allow the number of calibration points to increase to 100. The new mean and standard deviation may be slightly different from the old, since they are computed as data is taken, allowing no rejection of "bad" points during the summary calculation.

An extensive programmer's manual for Direct Connect was prepared. This includes a tutorial introduction, structure and flow charts, input/output format documentation, complete source code listings of

routines above the systems level, and pointers to other available information.

ORIGINAL PAGE 19  
OF POOR QUALITY

## 8. STATUS OF LASER UPGRADING

The ranging system shown in Figure 2 has a static pointing mount that is aimed by means of computed predictions of satellite azimuth and altitude. The predictions are computed and fed to the mount by minicomputer, which also collects and preprocesses the laser data on line. The system operates in both day and night conditions.

The laser transmitter is a Q-switched ruby oscillator with a pulse chopper and a single pass amplifier. The laser uses a Pockels Cell and a Brewster stack for a Q-switch; both oscillator and amplifier are mounted in double elliptical cavities, each containing two linear flashlamps. The optical cavity of the oscillator is formed by a flat rear mirror, with a reflectivity of 99.9%, and the uncoated front of the oscillator rod.

The chopper is a Krytron-activated Pockels cell with entrance and exit dielectric polarizers for the necessary transmission and isolation. The optical assembly of the chopper, which consists of a thin-film dielectric polarizer sharpener and analyzer, and a KD\*P 50 ohm Pockels cell, was designed to fit between the original laser oscillator and amplifier sections. A Blumlein circuit provides the proper high-voltage pulse to operate the Pockels cell and a PIN diode and avalanche transistor circuit trigger the system. The Blumlein is essentially a delay-line structure, in which delays and reflections are used to produce a high voltage rectangular pulse of desired width from a voltage step provided by the Krytron.

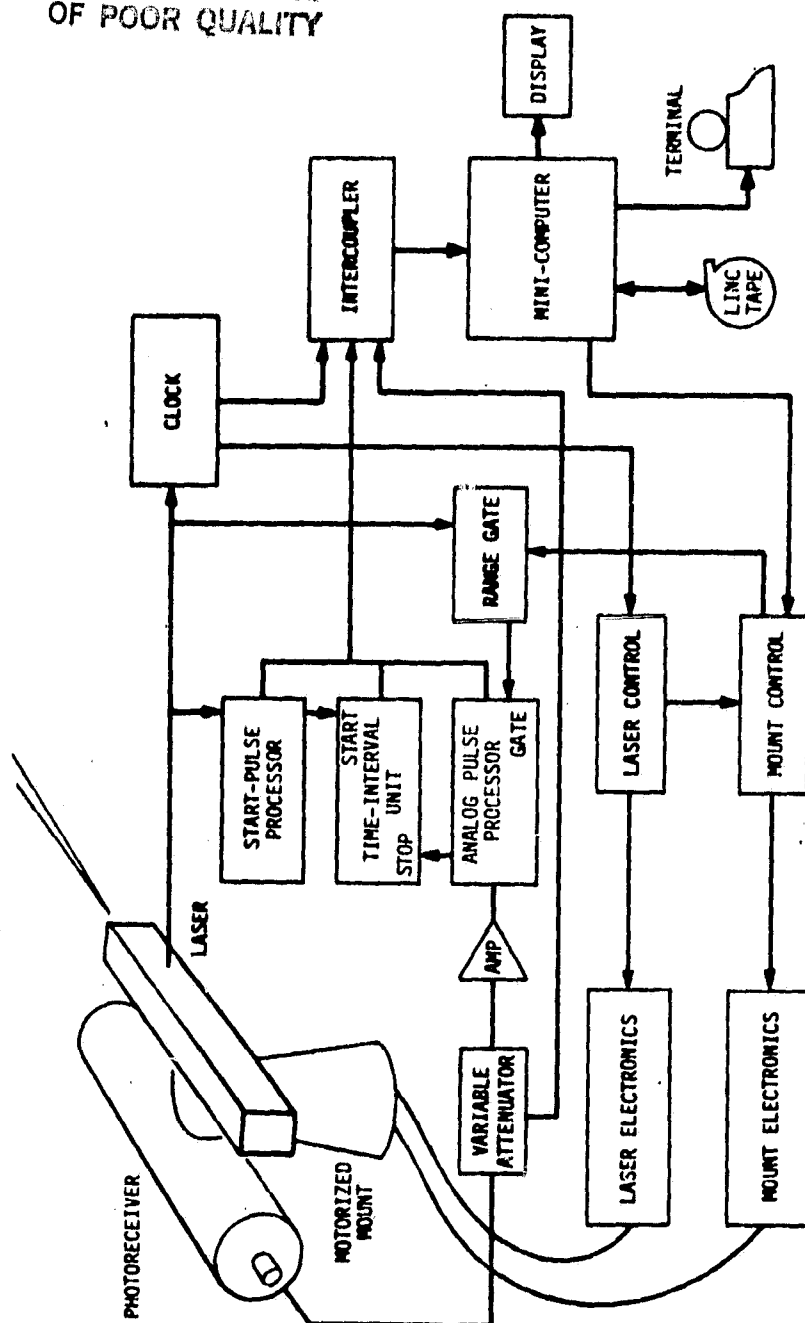
The laser output pulse is sampled by a Hamamatsu, S1188-01, PIN diode. The diode output is broadened to about 5 nsec with a combinational delay circuit and then applied to a constant fraction discriminator which furnishes the start pulse for the timing system. The broadening is required to place the constant fraction discriminator in a stable operating region.

The laser output pulse of 500 mj in 3 nsec (FWHA) passes through a Galilean telescope which is used to adjust output-beam divergence from 0.5 to 5.0 mrad. Normal operation is 0.5 mrad. The system operates at rates up to 30 ppm normally used on Lageos. The lower "faster moving" satellites are tracked at rates of 10-20 ppm depending upon orbital geometry.

The ranging system electronics (see Figure 2) consists of a clock, a firing control, a range-gate control, a processing system for the start and stop (return) pulses, a time interval unit, and a data-handling system, which feeds an on-line minicomputer. The clock, synchronized to within 1 microsecond of the station master clock, controls the firing rate; the time of the laser firing can be controlled by the laser control unit. The firing time can be shifted manually by multiples of 0.001 sec, with a maximum of 1 or 2 seconds, depending on the firing rate selected, to account for the early or late arrival of a satellite at a predicted point in its orbit. The range-gate control unit, which provides a gate to the counter and the pulse-processing system, is normally operated with a window of 200 nsec to 10 microsecond depending upon satellite and quality of prediction. The time-interval unit, with a resolution of 0.1 nsec, is triggered on and off by outputs from the pulse-processing system.

**Figure 2**  
Ranging System Electronics

ORIGINAL PAGE 13  
OF POOR QUALITY



To avoid accuracy limitations (aliasing) due to waveform sampling and to accommodate faster pulse repetition rates, SAO now uses an analog pulse detection system which consists of a matched filter tuned for the laser pulse. The filter is followed by a differentiator and slope-triggered low threshold discriminator, which functions essentially as a cross-over detector. The photo detector is an Amperex 2233B PMT and EMI Gencom base which has been modified by: (1) having the ground connection brought out to the PMT base and, (2) replacing the anode wire with 50 ohm cable. The PMT base was then laboratory tuned for minimum distortion of short duration low-level input pulses. The PMT and base configuration were selected as a low cost compromise between (1) fast risetime and good pulse reproduction and, (2) reliability and tolerance for high background noise (anode circuit). In addition, the front of the PMT has been apertured down to 1.5 cm to reduce jitter. This has reduced the jitter (peak to peak) from about 0.7 nsec to 0.4 nsec as measured with a 100 psec-wide optical pulse generator in the laboratory.

The azimuth-altitude static pointing mount has a pointing accuracy of better than  $\pm 30$  arcsec. The system is driven by stepping motors in an open loop mode, with the stepping motor drive system gears allowing for slewing speeds of 2 degrees/sec and positioning increments of 0.001 degrees. The mount has goniometers graduated to 0.001 degrees for reference and verification. Predictions, including pointing angles and range gate settings, are entered in the system on a point-by-point real time basis from the on line minicomputer.

The receiver is a 50.8 cm (20 inch) Cassegrain telescope with additional optics designed to focus an image of the far field onto the photocathode of the PMT. The photoreceiver has a fast shutter, a 3 Angstrom (Day Star) interference filter, adjustable field stops, and a provision for neutral density filters.

The laser stations have Data General Nova 1200 minicomputers for data processing and system control. The minicomputer has 32K words of 16 bit core memory and a hardware floating-point processor. Its peripherals include three block addressable magnetic tape units, alphanumeric CRT display units, a high speed paper tape reader and punch, and thermal printers with keyboards.

The minicomputer generates pointing predictions from orbital elements provided by Headquarters and feeds them to the laser in real time for pointing and range-gate adjustment. The minicomputer receives all incoming data on line from the laser system in real time and performs all of the computations for preprocessing and calibration. A second pass through the machine prepares the quick-look data message for transmission to SAO. The minicomputer provides detailed analysis of hardware (start and stop channel) and target calibrations as well as a review and summary of satellite and associated prepass and postpass calibration data on a pass-by-pass basis. During ranging operations, the operator has a real-time display of point and pass parameters, including return-pulse shape, output pulse parameters, range residuals to predictions, and data and hardware error diagnostics. Additional details on the SAO lasers are given in Pearlman et. al. 1973, 1975, 1978, 1981A.



A summary of the hardware status for upgrading the remaining systems is shown in Table 5.

The SAO 1 laser (formerly from Natal, Brazil) has been upgraded at SAO and will soon be installed near Matera, Italy under a cooperative arrangement with the Consiglio Nacional delle Richerche. Under this arrangement, the CNR will operate the laser with SAO providing technical support and coordination. Under the current plan, operations will commence by May 1983.

Table 5

Hardware Status

	<u>Laser Power Supply</u>	<u>Laser Control Unit</u>	<u>Range Gate</u>	<u>Photo receiver</u>	<u>Start Circuit</u>	<u>Analog Detector</u>
SAO 1	ready	ready	ready	ready	ready	ready
SAO 3	ready for mod.	built needs testing	ready for mod.	ready for mod.	ready	built needs testing

The upgraded work that was done on the SAO 1 system involved:

- A. Laser Power Supply - installation of new larger power transformers, rectifiers, silicon control rectifiers and rack rewiring.
- B. Laser Head - installation of new light detectors.
- C. Photoreceiver - internal modifications for the new lens system, shutter and interference filter.
- D. Data system electronics - the chassis that were reworked include:
  - 1. Laser Clock
  - 2. Range Gate Generator
  - 3. Tape Control
  - 4. R.F. Patch Panel
  - 5. Intercoupler
  - 6. Amp. Monitor Chassis
  - 7. Nim Bin Chassis

The above listed tasks will be performed on the SAO 3 system when it arrives from Australia in the early spring of 1983. All the pieces are on hand for the upgrading.

## 9. DATA QUALITY

The ranging performance capability of the laser in Arequipa has been assessed by examination of both systematic errors and range noise. These refer to performance of the ranging machine itself, leaving aside issues such as atmospheric correction, spacecraft center of mass correction, and epoch timing for discussion elsewhere.

### 9.1 Range Accuracy

The systematic errors of the laser system have been divided into three categories: spatial, temporal, and signal-strength variations (see Pearlman 1981A). Spatial variations refer to differences in time of flight depending on the position of the target within the laser beam. Temporal variations relate to system drift between pre-pass calibration and post-pass calibration. Variations in range due to changes in signal strength from pulse to pulse are a function of receiver characteristics.

#### Spatial Variations

Spatial variations, or the wavefront error, which arise from the multimode operation of the ruby lasers, have been measured at Arequipa during the last reporting period using a distant target retroreflector to probe the beam. Figure 3 shows the results for different ruby doping levels. The wavefront measurements on May 11 using the .03% Cr doped ruby rod show an r.m.s. variation across the wavefront of 1.4 cm and peak-to-peak variations of 4.5 and 5.0 cm. It appears however that a large

component of this variation is the temporal stability or measurement reproducibility as evidenced by the averaging of measurements at the beam center. . The results on June 4 using the .05% CR doped ruby are a little worse, showing r.m.s. wavefront distortion of 1.3 cm and 2.0 cm and peak-to-peak variations were of 5.3 cm and 6.9 cm. Once again, a significant component of the wavefront distortion measurement appears to be temporal variation, indicating that these wavefront measurements are probably giving an overestimation of wavefront distortion.

Figure 3.

ORIGINAL PART IS  
OF POOR QUALITY

WAVEFRONT MEASUREMENT AREQUIPA LASER									
DATE	TIME	SPACING BETWEEN POINTS (ARC MIN)	RUBY ROD DOPING	PRF (PER MIN)	AVERAGE* NUMBER OF PHOTOELECTRONS RECEIVED PER PULSE	TEMPORAL STABILITY AT BEAM CENTER		WAVEFRONT DISTORTION	
						RMS (CM)	MAXIMUM EXCURSION (CM)	RMS (CM)	MAXIMUM EXCURSION (CM)
MAY 11	03 HRS	.42	.03%	20	30	1.8	4.1	1.4	5.0
	05 HRS	.42		20	28	1.4	3.3	1.4	4.5
JUNE 4	03 HRS	.42	.05%	20	28	1.5	3.2	2.0	6.9
	06 HRS	.42		30	28	1.5	3.0	1.3	5.3

\*FIFTY PULSES AT EACH OF TWENTY POSITIONS

The difference between the .03% and .05% doping may not be statistically significant; but the lower doping probably allowed more uniform pumping which may have given a more uniform wave front (mode pattern).

### Temporal Variations

The temporal variations or system drift are estimated through electronic and ranging calibrations.

Electronic calibrations using a 3 nsec pulse through a fixed delay line to start and stop the ranging system were used at Arequipa during the previous reporting period to estimate the stability of the electronics. An example of the results are shown in Figure 4. The r.m.s. variation of the means is less than 1 cm with peak-to-peak values about 2 cm.

Temporal stability of the full system was measured with the billboard target, ranging over a period commensurate with a Lageos pass. The results are shown in Figure 5. The r.m.s. variation of the set means is 1.2 cm while the peak-to-peak variation is 4.6 cm, which is slightly higher than the electronics tests.

Temporal stability is also estimated by the difference between pre-pass and post-pass calibrations to the billboard target. These measurements are taken at about 5 photoelectrons with 50-100 calibration points in each calibration. Typical results for a one month period (see Figure 6) show an r.m.s. variation in pre-calibration minus post-calibration differences of about 2 cm.

Figure 4.

ORIGINAL FILED  
OF POOR QUALITY

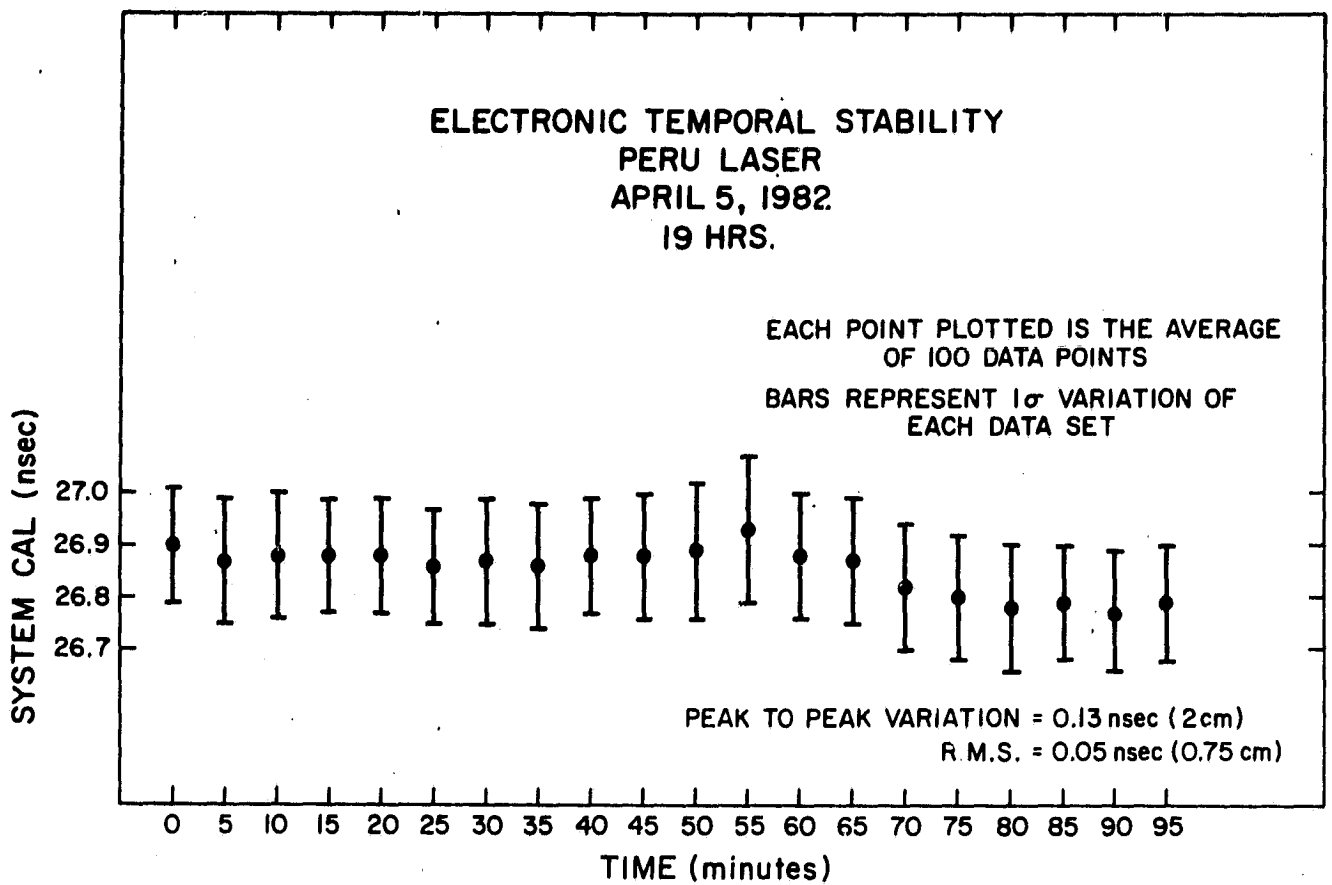


Figure 5.

ORIGINAL PAGE IS  
OF POOR QUALITY

TEMPORAL STABILITY  
BILLBOARD RANGING  
PERU LASER  
JAN 21, 1983  
01 HOURS

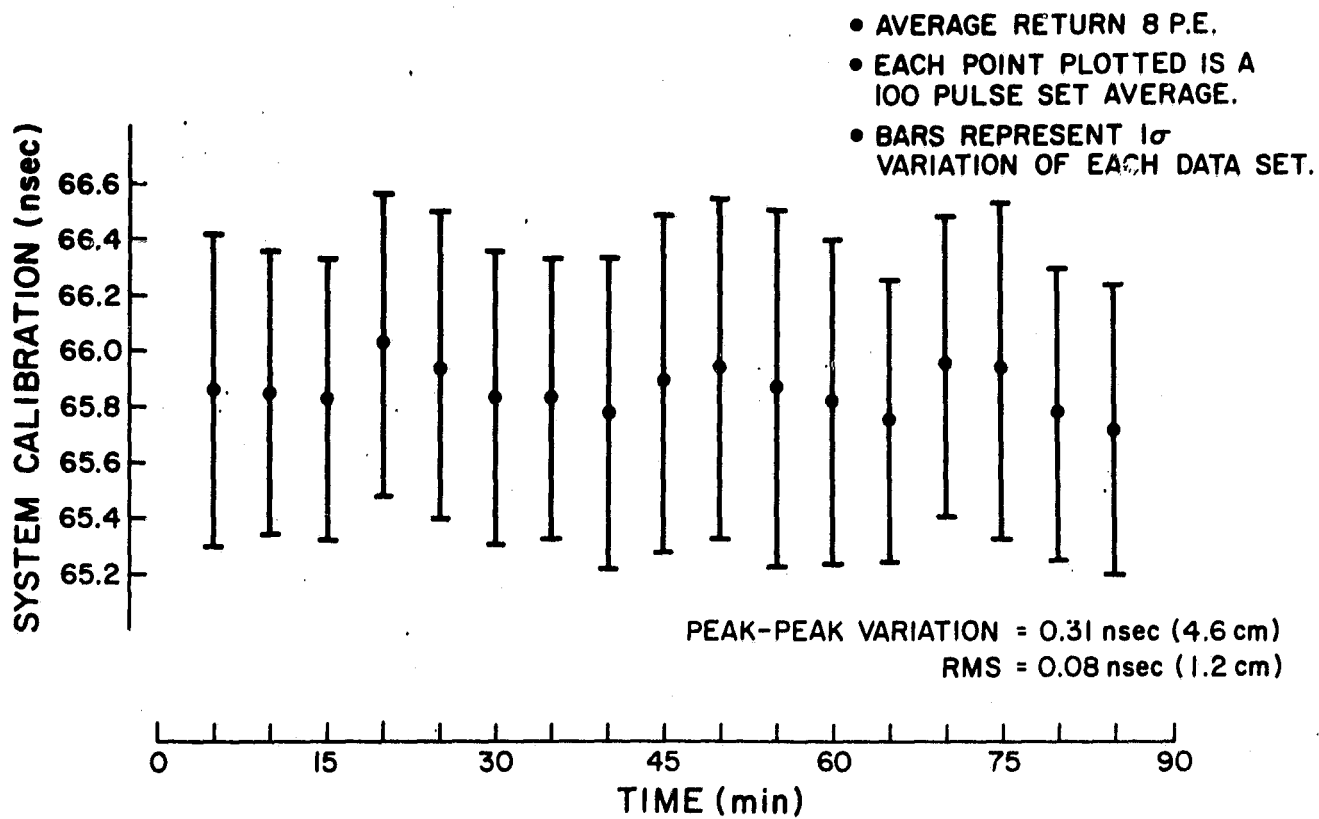
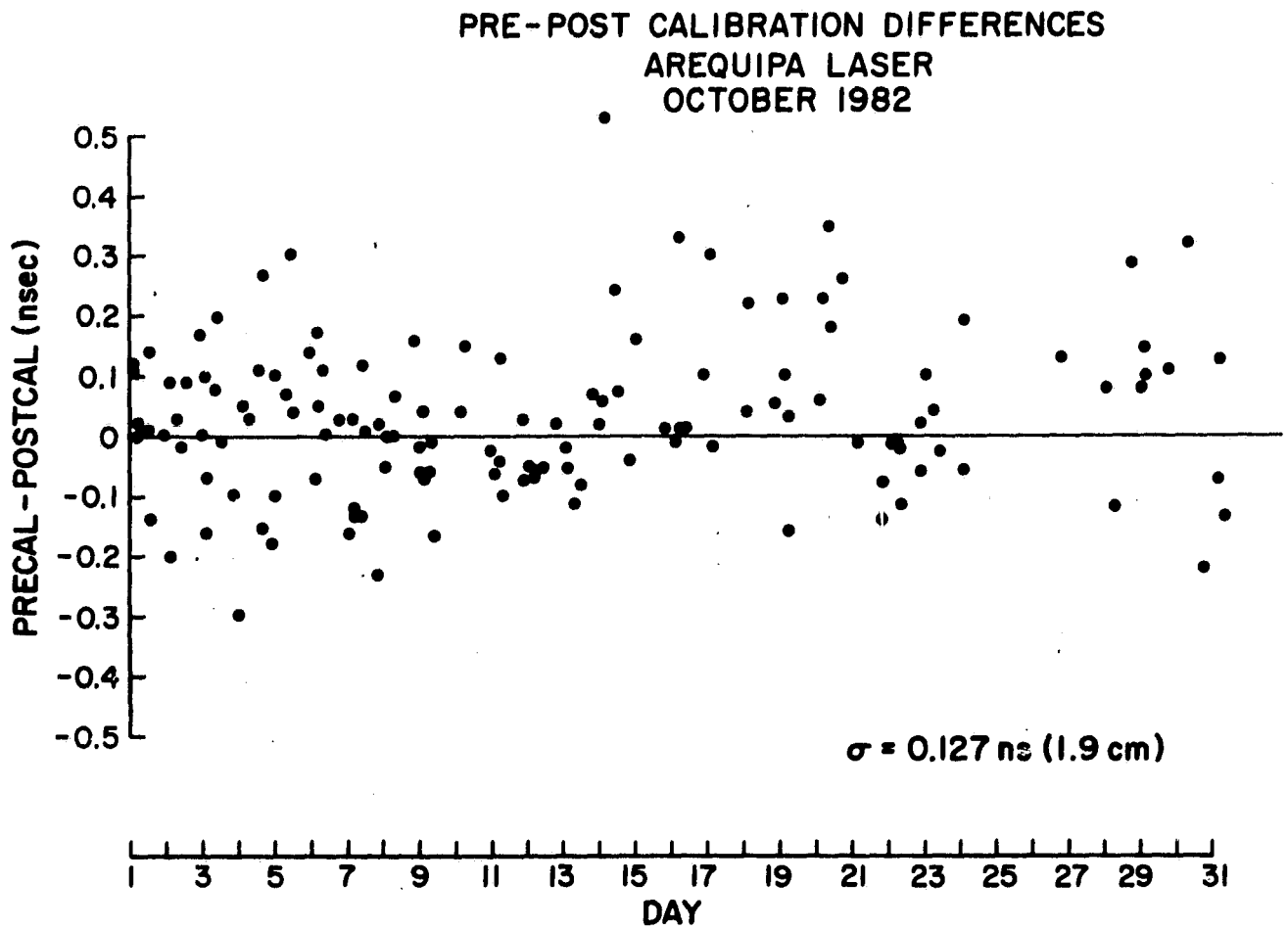




Figure 6.

ORIGINAL PAGE 19  
OF POOR QUALITY



### Signal Strength

The SAO lasers operate at the single photoelectron level on Lageos and in the range of 1-50 photoelectrons on low orbiting satellites. Variations in apparent range with signal strength have been examined with extended target calibrations over the dynamic range of the laser instrument (See Figures 7 and 8). The mean calibration over the operating range of 1-50 photoelectrons is typically flat to  $\pm 0.15$  nsec (2.2 cm) with maximum peak-to-peak excursion of 0.3 nsec (4.5 cm). We believe that the lowering trend at lower signal strengths is due to non-optimization of the matched filter. The matched filter was optimized for nearly symmetrical laser output pulse, whereas the single photoelectron pulses tend to be somewhat asymmetric.

A summary of the range error components are tabulated in Figure 9. Assuming that these errors are independent, the root-sum square (rss) error due to the r.m.s. systematic sources is about 4 cm. We use this value to characterize the systematic errors that can be expected for data averaged over a pass.

The long term stability of the system is shown in the history of calibration data taken over a period of a month (see Figure 10). During this time interval there appears to be a slight secular trend in the data probably due to equipment aging.

Figure 7

ORIGINAL PAGE 18  
OF POOR QUALITY

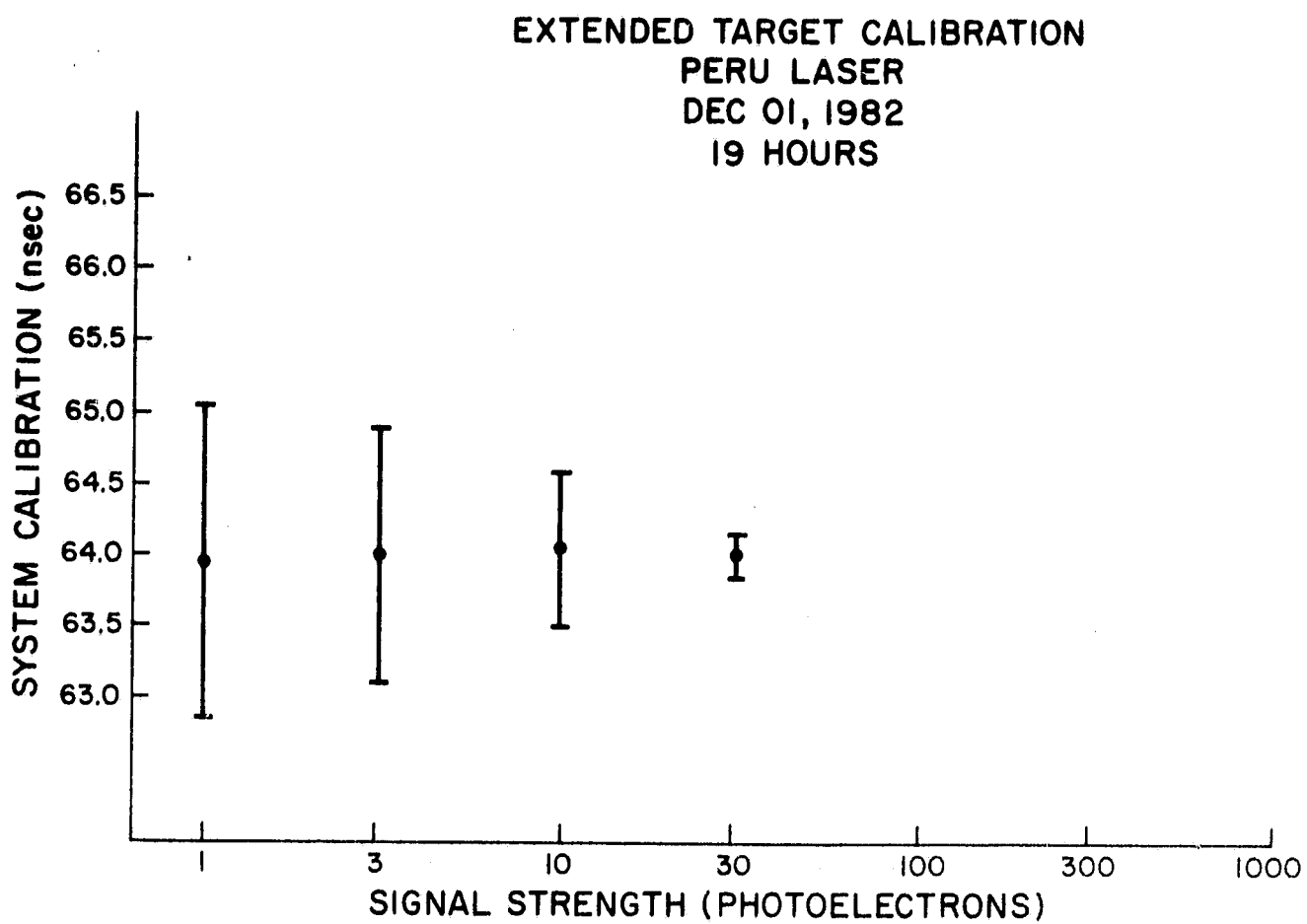


Figure 8

ORIGINAL PAGE IS  
OF POOR QUALITY

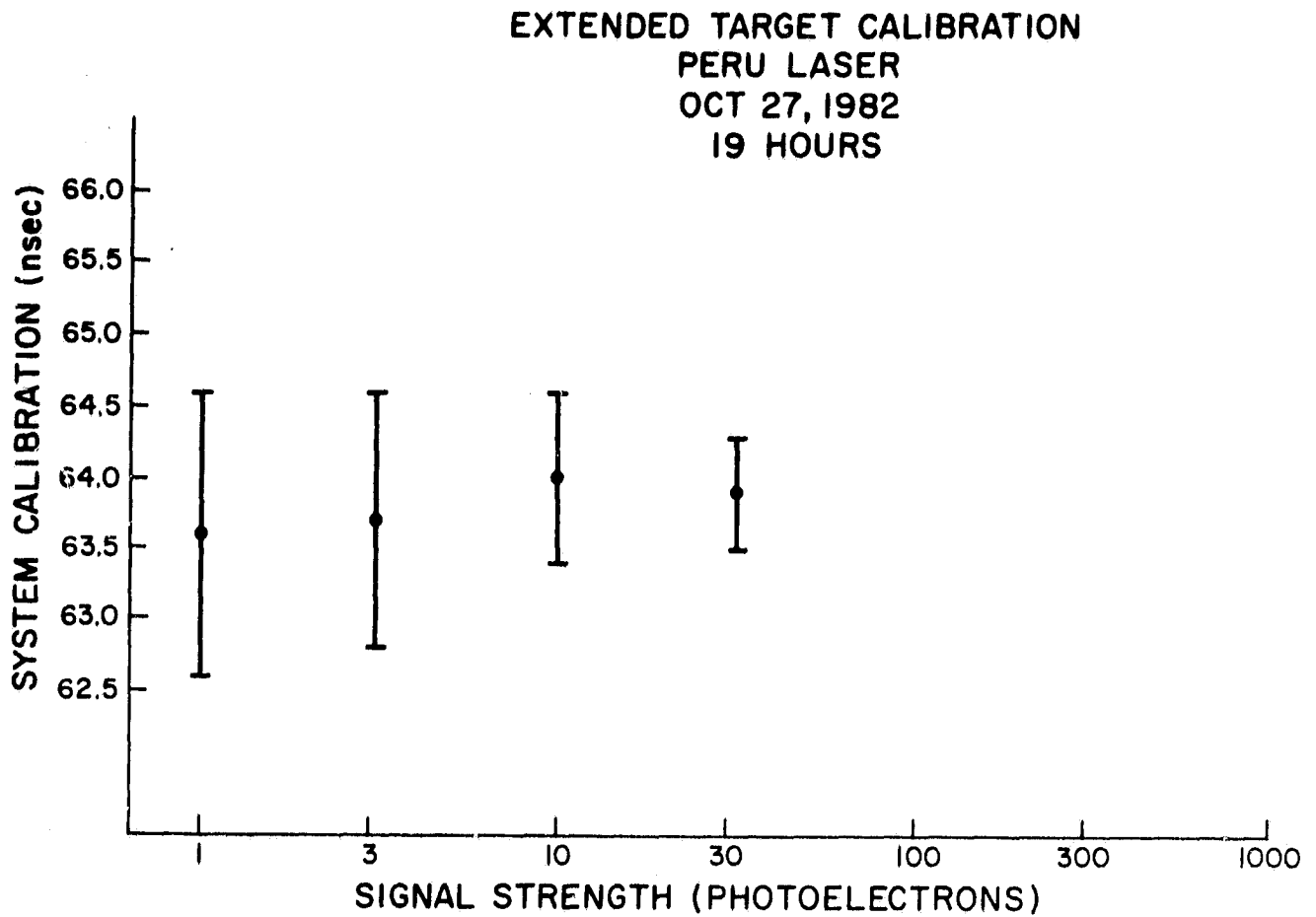


Figure 9

ORIGINAL VALUES  
OF POOR QUALITY

CALIBRATION AVERAGES  
AREQUIPA LASER  
OCTOBER 1982

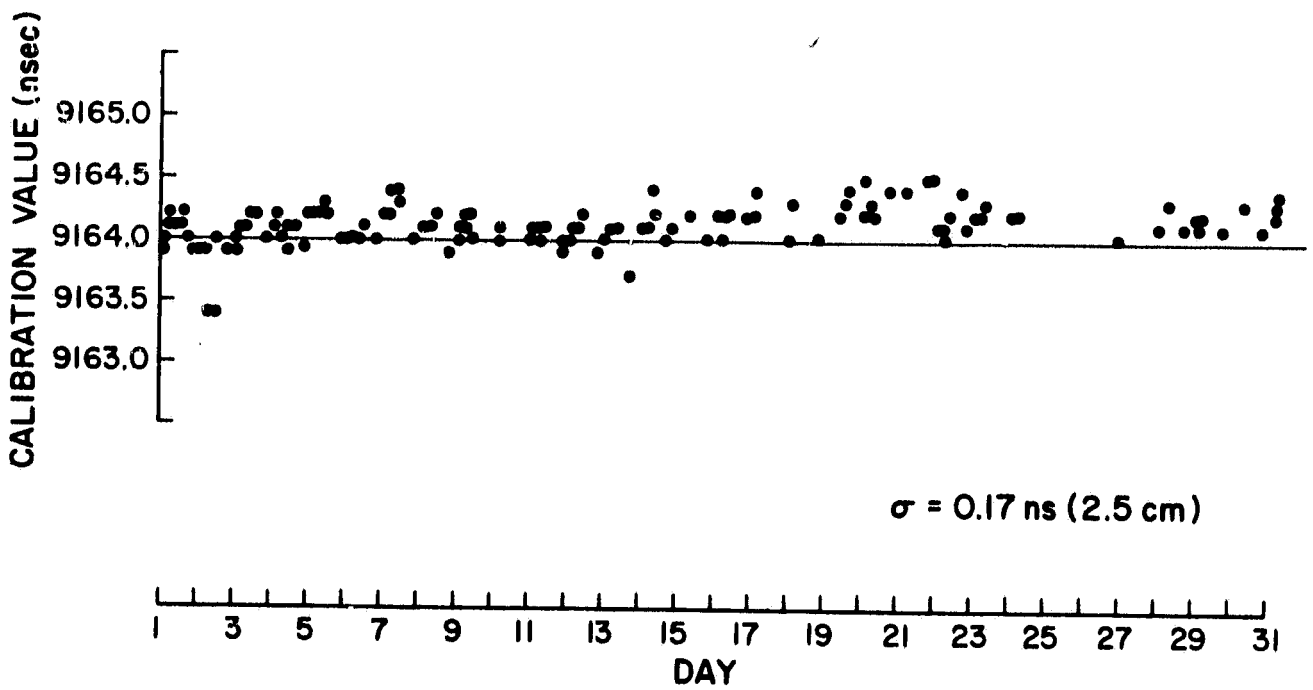


Figure 10

SAO LASER NETWORK  
SYSTEMATIC ERROR SUMMARY

SOURCE	EST. ERROR (RMS)	EST. ERROR (PEAK)
Wavefront (Spatial)	2.0 cm	5.0 cm
System Drift (Temporal)	2.4 cm	6.0 cm
Calibration (Signal Strength)	<u>2.2 cm</u>	<u>4.5 cm</u>
R.S.S.	3.8 cm	9.0 cm

## 9.2 System Noise

The noise performance of the system was measured during the previous reporting period by examining range noise ( $1\sigma$ ) verses signal strength in calibration runs on the billboard target. This has the advantage of highlighting system jitter by averaging out effects of wavefront distortion. The results of several calibration sequences are shown in Figure 11, along with the theoretical results for a 3 nsec gaussian pulse for reference. At low and intermediate signal strengths, the range noise follows closely the anticipated  $n^{-1/2}$  dependence and is consistent with a pulse of about 3 nsec width. At high signal strengths, the system noise levels off at about 0.2 nsec (3 cm) which is probably dominated by the jitter in the P.M.T.

The distribution of range residuals ( $1\sigma$ ) on a per pass basis for Lageos, Starlette, and BE-C at Arequipa during this reporting period are shown in Figures 12, 13 and 14. Range noise on Lageos varies typically from 13-18 cm as would be anticipated for 1-2 photoelectron events with a 3.0 nsec wide pulse. There is probably some corruption due to the jitter in the electronics and the PNT.

ORIGINAL PAGE IS  
OF POOR QUALITY

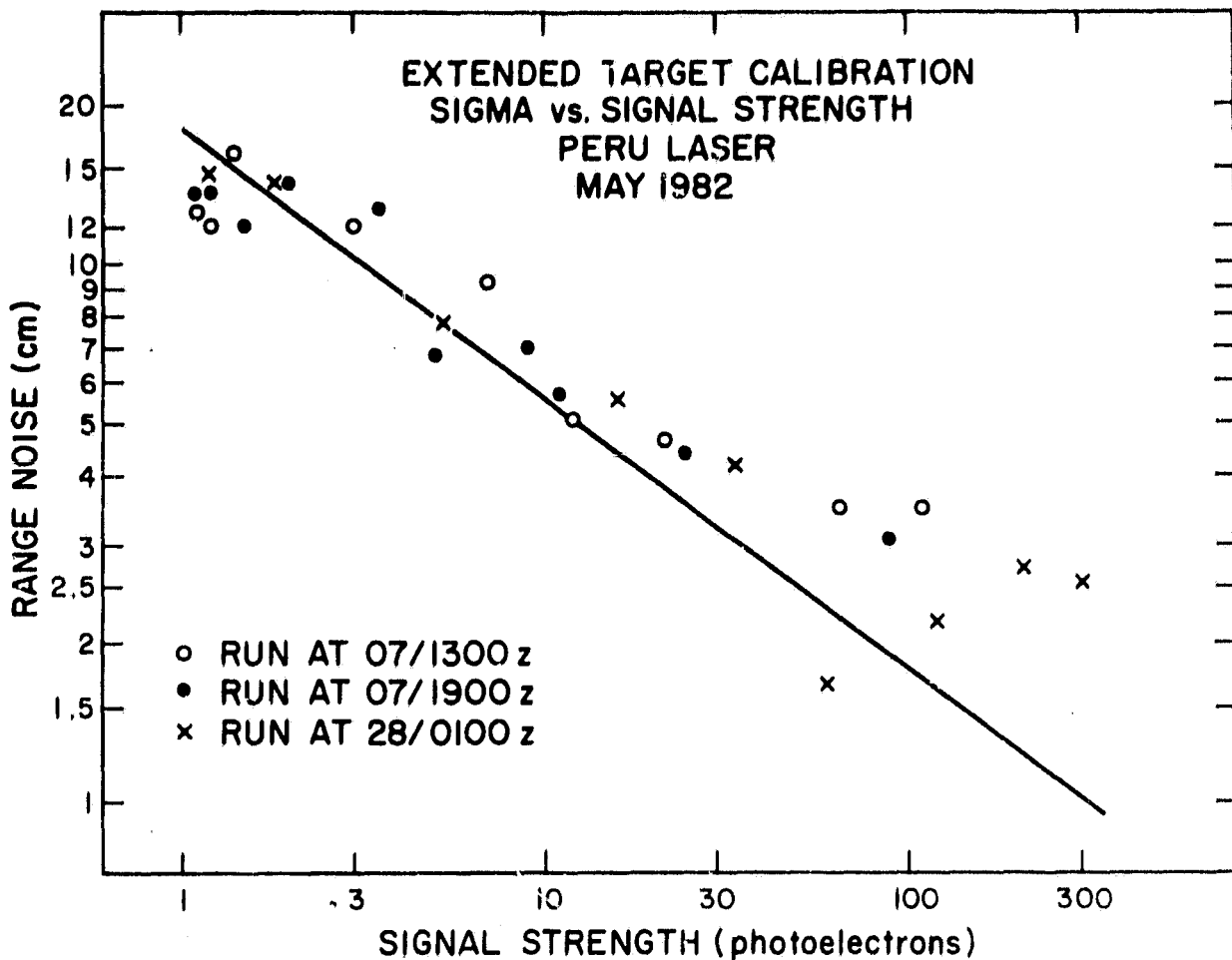




Figure 12

ORIGINAL PAGE IS  
OF POOR QUALITY

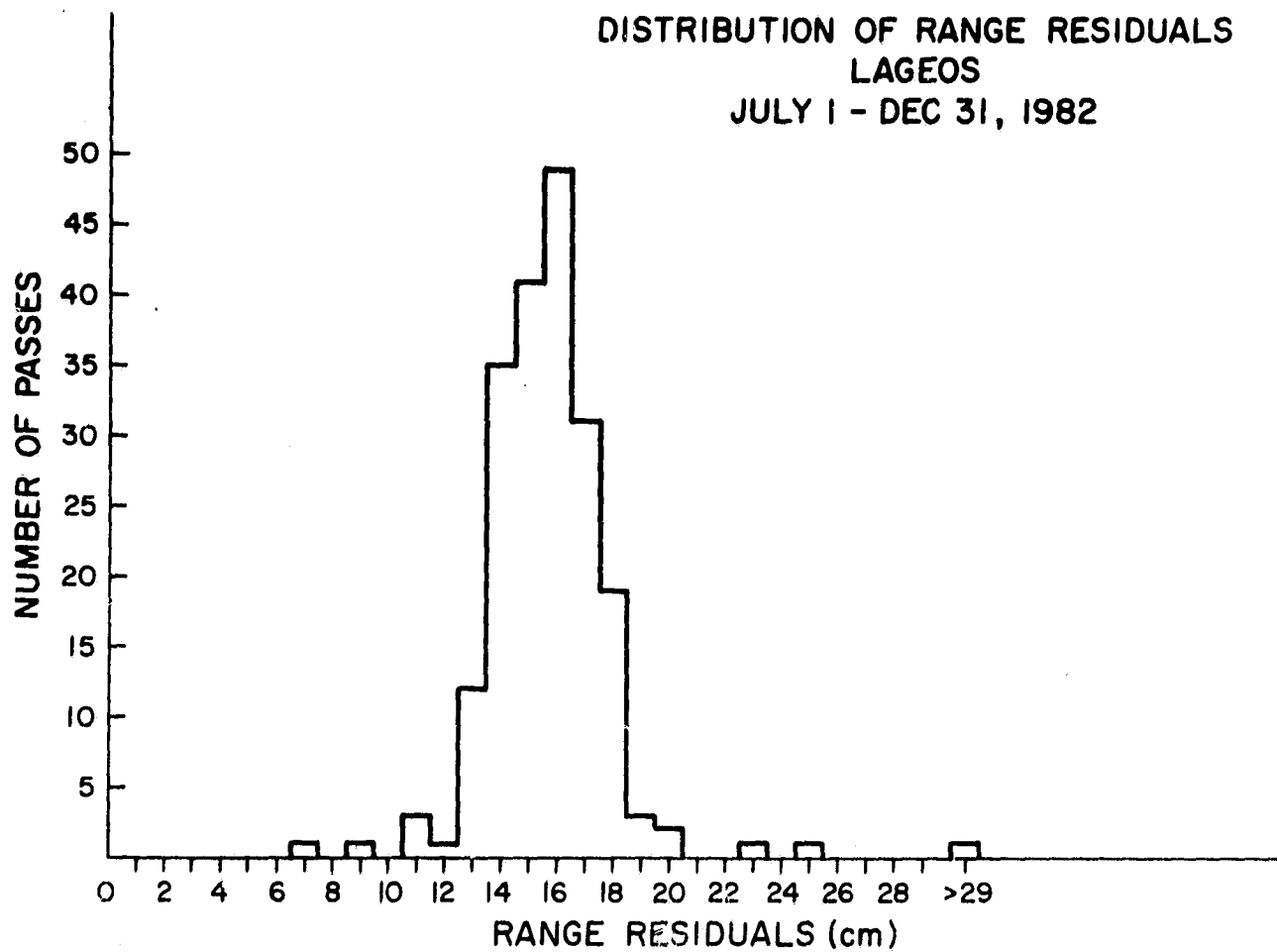


Figure 13

ORIGINAL QUALITY  
OF POOR QUALITY

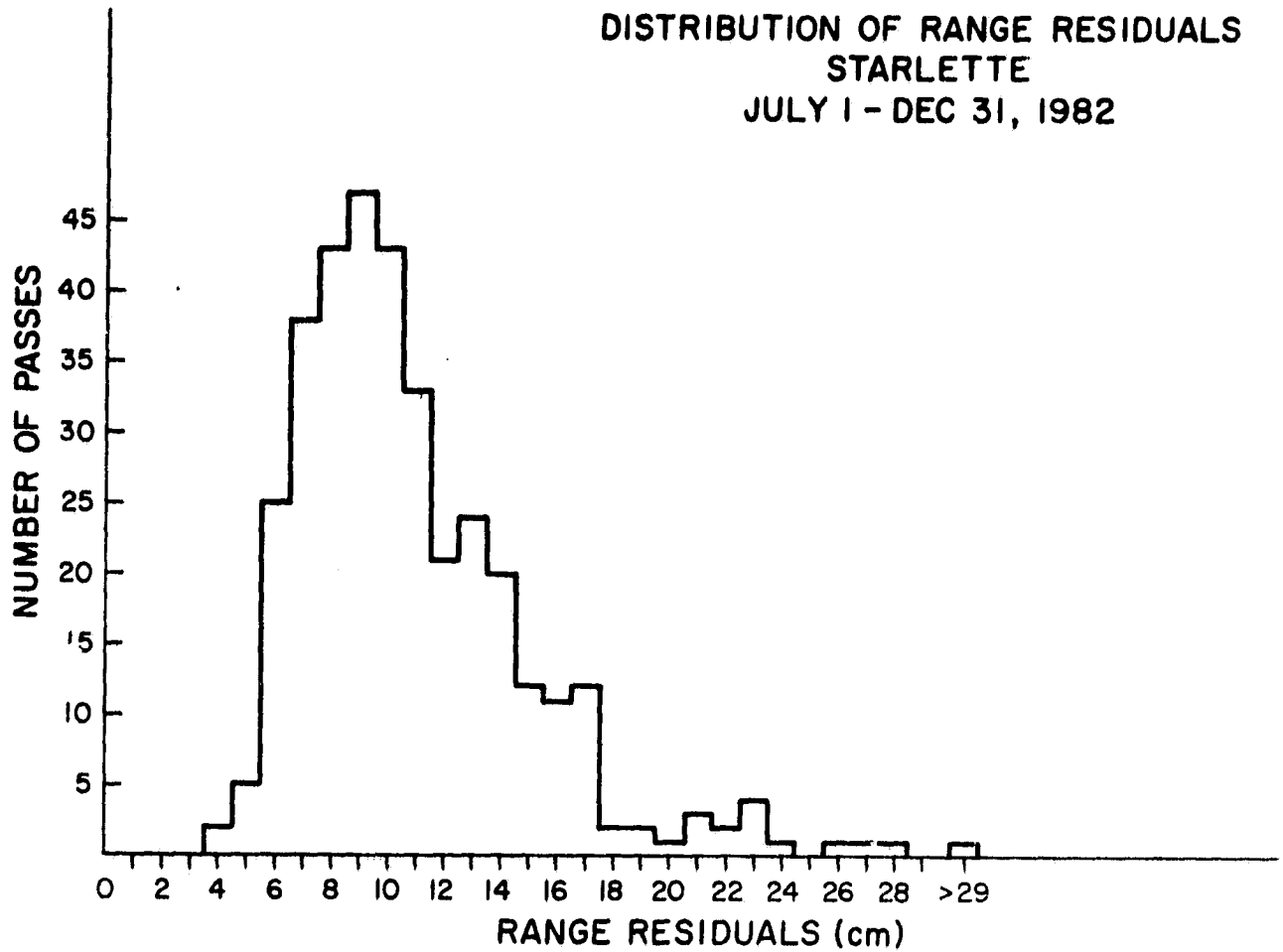
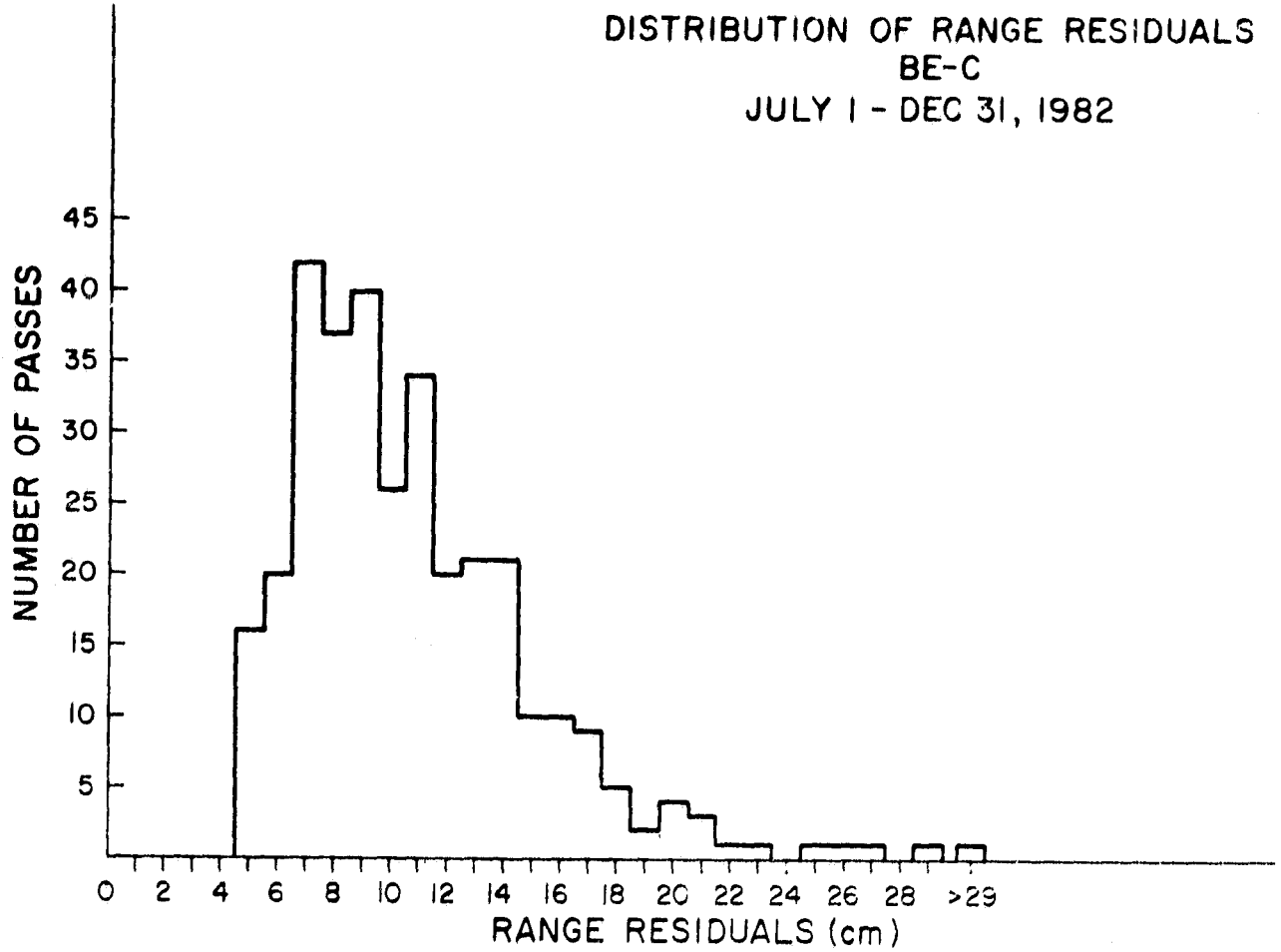


Figure 14

ORIGINAL PAGE IS  
OF POOR QUALITY



On the lower satellites, return signal strengths are typically 5-30 photoelectrons. Short arc fits to quick-look data give r.m.s. values of 6-18 cm. At the higher signal strengths, the range jitter in the PMT and the electronics becomes significant and tends to degrade the  $n^{-1/2}$  noise dependence.

## 10. RELOCATION OF SAO 1 TO MATERA, ITALY

In early 1982, NASA, SAO and representatives of the Italian National Space Council (a part of the CNR) agreed on the relocation of SAO 1 to Italy. Under the agreement reached, the laser was to be relocated to a mutually-agreed upon site at CNR expense and they would take responsibility for operations. SAO would provide headquarters support, configuration control, and network integration and coordination.

Based on weather data, seismology, logistics and support considerations and geographic location, a site about 10 miles west of Matera was selected. Detailed information on cloud cover and a trip report by SAO representatives who visited the site in April 1982 was included in the last semi-annual report. A building design was submitted to SAO by the CNR in June 1982. The design was approved with minor modification in July 1982.

The current schedule, shown in Figure 15, projects an operational date of 1 July 1983, after a 3 month set up, testing, and training period. The pacing item at the moment is the completion of the laser building by the Italian Contractors.

During this reporting period, construction got underway on both the service building and the laser building at the site. As of late December, the roof and walls were being placed on the Service building. The foundation had been laid for the laser building and work was underway on the laser pier. The projected schedule for building completion is shown in Figure 15. The service building is to be ready for occupancy in early

February; the laser building will be ready in mid-March.

The first shipment containing the laser mounting hardware (for the pier) and electrical fixtures was sent by air freight in late November and received in early December. The bulk of the equipment was sent by sea freight in early January and is due in mid-February. A third shipment, containing the minicomputer and the time interval unit will be sent by air in mid-February.

Three Italian observers have spent six weeks of rigorous field training in Arequipa (November-December 1982). They are scheduled to come to SAO for three weeks in February 1983 for some exposure to the Headquarters Operations. Two additional observers will go to Arequipa in February to gain some operational experience.

Based on the current schedule, two SAO engineers will arrive in Matera in early March to begin unpacking and testing at the chassis level. This work will be carried out in the service building, until the laser building is completed. By late March, installation of the laser on the pier should be underway.

Temporary power will be available at the station until mid-May when full commercial power is to be installed. The CNR is also making arrangements for communications through telex and ESA to be available this spring.

A plan for station timing was developed by CNR and SAO. We plan to use the dual channel EEC0 clock with a LORAN-C receiver and a TV synchronization monitor which should be compatible with 1 microsecond timing.

It is anticipated that the SAO engineers will be on site until early July when the operations phase gets underway.

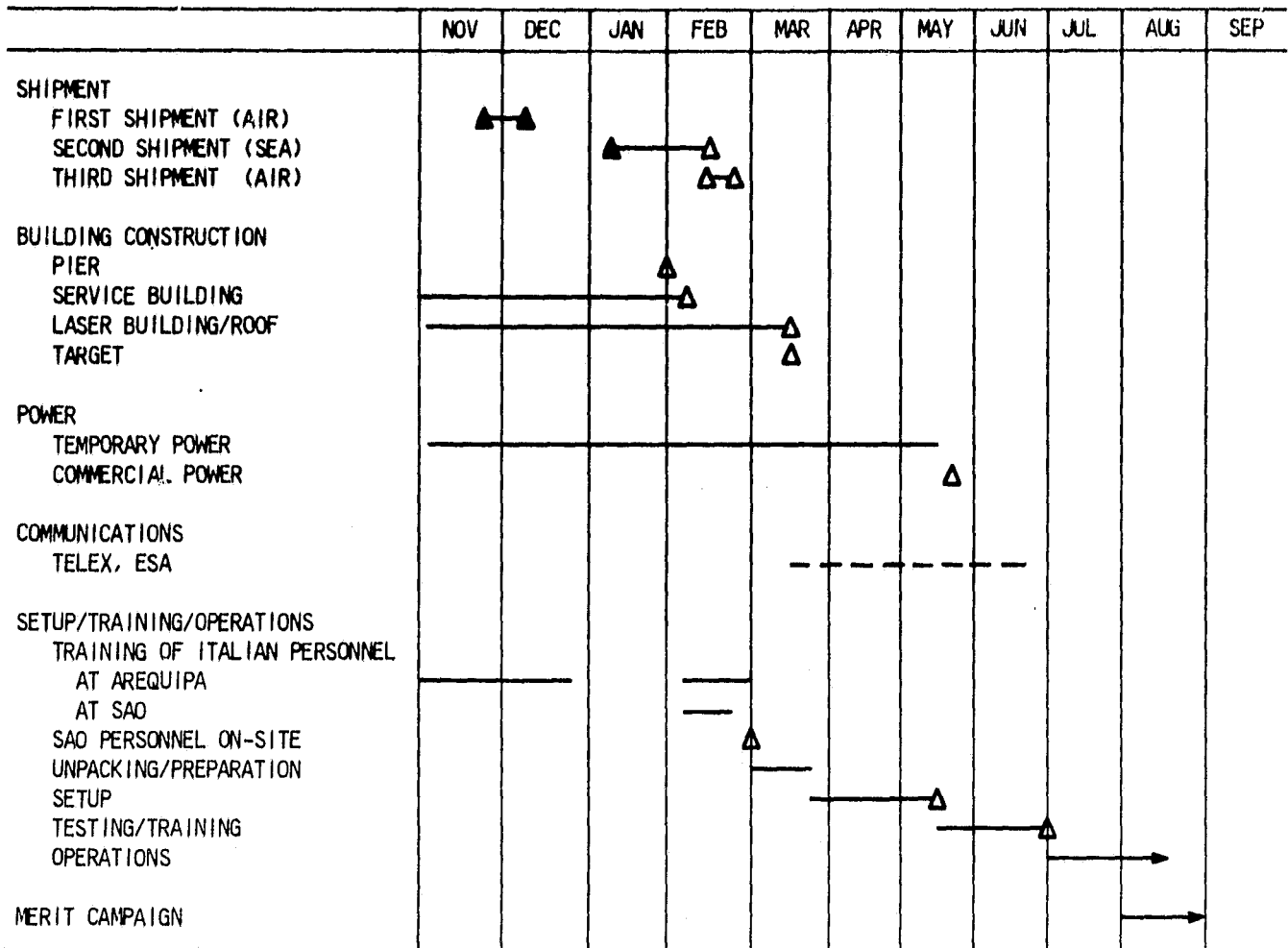
An agreement between SAO and the CNR covering our basis of understanding at the working level (see Appendix 2) has been sent to the CNR for signature.

Figure 15

Schedule for Matera Installation

OF POOR QUALITY

SCHEDULE FOR  
MATERA INSTALLATION





## 11. STATUS OF SAO 3 AND 4

The laser system from Orroral Valley (SAO 3) is in the process of being returned to SAO. Several key items from the system, the minicomputer and the time interval counter have been received and tested in Cambridge and will be sent to Matera as the primary units. The remainder of the Orroral Valley equipment will be upgraded and then placed in storage.

The system electronics and minicomputer from the Mt. Hopkins laser (SAO 4) have been returned to Cambridge and have been set up as a laboratory and diagnostic test facility for the other lasers. The rest of the equipment including the laser, the photoreceiver, and the mount will remain in storage at Mt. Hopkins.

Packages for upgrading both of these systems have been built and will be tested in early FY83. Both systems are available for relocation and discussions are underway to seek new locations.

## 12. PERSONNEL

### 12.1 TRAVEL

Dr. Michael R. Pearlman travelled to Goddard Space Flight Center for a few days to attend the Third Joint NASA/PSN Lageos II Working Group Meeting in October. Later in that month, he returned to Goddard to attend the Crustal Dynamics Working Group meetings.

He later travelled to Rome, Italy to attend the Lageos meeting held there on the 18th of November. He also travelled to the location of the new laser tracking site near Matera and met with administrative personnel there. The station will be run by the Consiglio Nazionale delle Ricerche with contractor support from Telespazio.

Also during November, Mr. Sacchini, Mr. Dal Rosso, and Mr. Cenci, three Telespazio personnel, travelled to Arequipa for a period of 6-8 weeks to get a working knowledge and hands on training at the station. This trip was supported by Italian funds.

In December, Dr. Pearlman travelled to San Francisco, California to attend the winter meeting of the American Geophysical Union, sessions on Review of Geodesy During the International Geophysical Years. While there, he gave a presentation and paper entitled the Early Experience of the SAO Satellite Tracking Program.

At various times during the reporting period, Dr. Michael R. Pearlman and other personnel travelled to Goddard Space Flight Center to attend Laser Network Operations Meetings and for general network operations and technical discussions.

## 12.2 VISITORS

Dr. Barbara Kolaczek, a visiting scientist from the Polish Academy of Sciences, Space Research Center of Warsaw, Poland, who arrived at SAO in June, continued her research on a cooperative program for Polar Motion Analysis thru mid August. Upon leaving SAO, she travelled to Greece to attend the IAU General Assembly to give a presentation entitled "Local Variation of Latitude". This work is sponsored by PL-480 "Excess" Currency and Polish Cooperating agency funds.

## 12.3 PERSONNEL

Mr. Julian Simms, Station Manager from the Orroral Valley, Australia site, has been reassigned to headquarters due to the station close-out. Mr. Simms is currently working as an engineer in the Satellite Tracking Program; he and his family relocated to Massachusetts in the beginning of July.

## REFERENCES

- Pearlman, M. R., J. M. Thorp, C. R. H. Tsiang, D. A. Arnold, C. G. Lehr, and J. Wohn, SAO network: Instrumentation and data reduction In 1973 Smithsonian Standard Earth (III), ed. by E. M. Gaponchkin, Smithsonian Astrophys. Obs. Spec. Rep. No. 353, pp. 13-04, 1973.
- Pearlman, M. R., C. G. Lehr, N. W. Lanham, and J. Wohn, Upgrading of the SAO laser systems to improve ranging performance. Presented at the Workshop on Laser Tracking Instrumentation, Prague, Czechoslovakia, August; also in Laser Tracking Instrumentation, ed. by G. C. Weiffenbach and K. Hamal, Tech. Univ. of Prague, Prague, Czechoslovakia, 1975.
- Pearlman, M. R., N. W. Lanham, J. Wohn, J. M. Thorp, E. Imbier, F. D. Young, J. Latimer, and I. G. Campbell, A report on the Smithsonian Astrophysical Observatory laser ranging systems. Presented at the Third Workshop on Laser Ranging Instrumentation, Lagonissi, Greece, May 1978.
- Pearlman, M. R., N. Lanham, J. Wohn and J. Thorp, Current Status and Upgrading of the SAO Laser Ranging Systems Presented at the Fourth International Workshop on Laser Ranging Instrumentation, Session I, in Austin, Texas, October 1981.

STUDY OF THE  
TIME EVOLUTION OF THE LITHOSPHERE

Grant NAG 5-150

SemiAnnual Progress Report No. 3  
For the period 1 March 1982 - 31 August 1982

Principal Investigator  
Dr. Micheline C. Roufousse

Prepared for  
National Aeronautics and Space Administration  
Goddard Space Flight Center  
Greenbelt, Maryland 20771

November 1982

Smithsonian Institution  
Astrophysical Observatory  
Cambridge, Massachusetts 02138

The Smithsonian Astrophysical Observatory and the Harvard College Observatory are members of the Center for Astrophysics
---

The NASA Technical Officer for this grant is Mr. Jean Welker, Code 921,  
Earth Survey Applications Division, Application Directorate. Goddard  
Space Flight Center, Greenbelt, Maryland 20771.

## Semiannual Progress Report

### Study of the Time Evolution of the Lithosphere

During the last reporting period, we have started a comprehensive study of all seamounts. The SeaSat data which had been completely organized and edited in previous reporting periods were used. In order to retain maximum accuracy, the data are being retrieved on a track-by-track basis in restricted geographical areas; these are then corrected manually in order to reduce cross-over errors. This method is possible for small geographical areas. In this manner, we are able to keep the accuracy of the track-by-track basis for linear features, but we have the flexibility of a two-dimensional network for more complex situations. We are in the process of producing local geoid maps for all of these regions. At the same time, we filter the data for long wavelength trends by removing a reference geoid of degree and order 10 calculated with the GEM9 coefficients.

At this point, we have retrieved all available data over the Ninety East Ridge, Kerguelen, Hawaiian-Emperor and Walvis, and we are in the process of identifying and obtaining the best set of bathymetry data in each case. We are at the same time preparing a series of filters in wave number space, both for the thin elastic plate and the Airy models. As soon as the bathymetry is digitized and, hopefully, corrected for sediments and sediment loading, we shall be able to study in detail the mechanism for crustal loading in each case.

DEVELOPMENT OF IMPROVED  
MODELS OF THE THERMOSPHERE AND EXOSPHERE

Quarterly Progress Report No. 5

For the period 1 April 1982 through 30 June 1982

Contract F19628-81-K-0033

Principal Investigator

Mr. Jack W. Slowey

October 1982

This report is intended only for the  
Internal Management use of the Contractor and the Air Force

Prepared for

Air Force Geophysics Laboratory  
Hanscom Air Force Base, Massachusetts 02731

Prepared by

Smithsonian Institution  
Astrophysical Observatory  
Cambridge, Massachusetts 02138

<p>The Smithsonian Astrophysical Observatory and the Harvard College Observatory are members of the Center for Astrophysics</p>
---

## 1. Introduction

Work under this contract is directed toward the development of improved models of the temperature, density, and composition of the earth's thermosphere and exosphere. The major emphasis at present is on the large spatial and temporal variations in these quantities that are associated with geomagnetic disturbances. Work in progress involves the analysis of a large body of neutral mass-spectrometer data and the development of an improved model of the geomagnetic variation in the atmosphere based on this analysis.

## 2. Scientific Progress

We continued to work in two main areas. The first of these is the development of a practical model to take into account the persistence in the effects of geomagnetic disturbance which, as mentioned in our last report, we have observed in the ESR04 mass-spectrometer data. The second area is the processing of the data from the Atmosphere Explorer-C (AE-C) satellite that we received some time ago from the National Space Data Center (NSDC).

Concerning the development of a model to take the persistence into account, we have implemented the use of an exponentially-weighted mean value of the  $K_p$  geomagnetic index taken over the interval preceding the time in question. We have been using this to derive, by trial-and-error, preliminary values of both the delay time and the time constant for the decay and to see how well we can fit the observed variations with this formulation.

Concerning processing of the AE-C data from NSDC, there has been a delay due to the fact that some of the programs that we developed earlier, independently of the present contract, seem to have been lost. We do, however, have a complete record of our previous work on data tapes in the same format and are in the process of reconstructing the missing programs. We plan to transcribe all of the OSS mass-spectrometer data from the NSDC tapes for use on our computer at SAO. We then plan to archive the entire data set, which presumably contains the data from all of the AE-C experiments, at AFGL. The original tapes will then be returned to NSDC.

## 3. Future Plans

As mentioned in our last report, we hope to soon be able to publish some of the results of our studies of the time lag and persistence in the geomagnetic variation. Also as mentioned before, we plan to begin work on a new model of the geomagnetic variation that will include a better representation of the



latitudinal form of the variation and that will include the variation with local time. We also hope to be able, before long, to begin work on improving the empirical models of some of the other variations in the thermosphere and exosphere.

4. No research failed during this reporting period.

5. The paper that Mr. Slowey presented at the SESC Workshop on Satellite Drag, entitled "Empirical modelling of the geomagnetic variation in the thermosphere", was published in the Proceedings of the Workshop. Mr. Slowey also presented a paper, titled "The geomagnetic variation in the Upper Atmosphere", at the COSPAR meeting in Ottawa in May. This paper has been accepted for publication in Advances in Space Research.

6. There were no visitors to our facility in relation to the contract effort during the reporting period.

7. Mr. Slowey attended a Technical Interface Meeting at AFSCF, Sunnyvale, California, in April for the purpose of providing advice on the selection of atmospheric models in AFSCF's Data System Modernization. He also attended the COSPAR meeting in Ottawa in May. Travel expenses for the Ottawa trip were paid by a grant from the Smithsonian Institution.

8. No personnel changes or important administrative action took place during the reporting period.

#### 9. Fiscal Information

Of the total funding of \$67,000 authorized for the research to date, about \$66,836 has been expended as of 30 June 1982. The FY 1982 portion of the work is complete. The total contract value of the work is \$128,000 for the period 1 April 1981 through 31 March 1984.

# 10. Cost Data

Cumulative Cost Data as of 30 June 1982

<u>Labor Elements</u>	<u>Planned Labor Hours</u>	<u>Amount</u>	<u>Actual Labor Hours</u>	<u>Amount</u>
Project Scientist	1,715	\$ 44,557	1,715	\$ 44,557
Programming/Data Handling	-	-	-	-
Other	4	45	4	45
<b>Total Labor</b>	<b>1,719</b>	<b>\$ 44,602</b>	<b>1,719</b>	<b>\$ 44,602</b>

## Other Expenses

Material and Miscellaneous	\$ 5,061
Computer	-
Travel	1,357*
<b>Total Other Expenses</b>	<b>\$ 6,418</b>
<b>Total Direct Cost</b>	<b>\$51,020</b>
<b>Indirect Cost</b>	<b>15,816</b>
<b>Total Cost</b>	<b>\$66,836</b>

\* Includes \$655 reallocated from Fiscal Year 1982 budget to support AFGL required travel of Mr. J. Slowey to Sunnyvale, California, Air Force Satellite Control Facility, to attend conference on Atmospheric Models + Orbit Calculation. The FY83 travel requirement will be reduced commensurately. Total Contract allocation of \$128,000 remains unchanged.

ORIGINAL  
OF FOUR COPIES

11. Planning Estimate as of 30 June 1982

Reporting Period

	Actual				Actual				Actual				Planned			
	Hrs.	Amt.	Hrs.	Amt.	Hrs.	Amt.	Hrs.	Amt.	Hrs.	Amt.	Hrs.	Amt.	Hrs.	Amt.	Hrs.	Amt.
Planned percentage of technical completion		36%				50%				78%				100%		
Labor Elements																
Project Scientist	710	\$ 16,252	186	\$ 5,528	456	\$12,646	363	\$ 10,130	-	\$ -	-	\$ -	-	\$ -	-	\$ -
Programming/Data	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Other	3	29	(1)	(11)	2	28	-	-	-	-	-	-	-	-	-	-
Total Labor	713	\$ 16,281	185	\$ 5,517	458	\$12,674	363	\$ 10,130	-	\$ -	-	\$ -	-	\$ -	-	\$ -
Other Expenses																
Material and Miscellaneous		\$ 2,089		\$ 1,424		\$ 656		\$ 892		\$ -		\$ -		\$ -		\$ -
Computer		-		-		-		-		-		-		-		-
Travel		-		429		669		259		-		-		-		-
Total Other Expenses		\$ 2,089		\$ 1,853		\$ 1,325		\$ 1,151		\$ -		\$ -		\$ -		\$ -
Total Direct Cost		\$18,370		\$ 7,370		\$13,999		\$11,281		\$ -		\$ -		\$ -		\$ -
Indirect Cost @ 31%		5,694		2,285		4,340		3,497		-		-		-		-
Grand Total		\$24,064		\$ 9,655		\$18,339		\$14,778		\$ -		\$ -		\$ -		\$ -

12. No property or equipment was acquired or developed during this reporting period.

13. No difficulties were encountered during the reporting period.

Appendix 2

AGREEMENT

between

SMITHSONIAN ASTROPHYSICAL OBSERVATORY  
OF THE UNITED STATES OF AMERICA

and

CONSIGLIO NAZIONALE DELLE RICERCHE (CNR)  
OF ROMA, ITALY

for the

SET UP AND OPERATION OF A  
SATELLITE LASER RANGING SYSTEM

This agreement, entered into this \_\_\_\_\_ day of \_\_\_\_\_ 1982 by the Smithsonian Astrophysical Observatory, hereinafter referred to as SAO, and the Consiglio Nazionale delle Ricerche, hereinafter referred to as CNR, does WITNESS that parties hereto agree as follows:

SAO RESPONSIBILITIES

Station Set up

On a cost reimbursement\* basis SAO will:

1. Pack and ship a fully operational laser ranging system to the agreed site.
2. Provide the latest field software in use with the other SAO lasers.
3. Provide the necessary manpower to set up the laser and upgrade the system as per the latest SAO modifications (already installed at Arequipa and Mt. Hopkins).
4. Provide manpower, on an interim basis as agreed, to train Italian personnel at the site and to assist in the transition to a fully operational station. It is anticipated that this will require a maximum of 2 man months after the laser is operational.
5. Provide on site training in Cambridge and at a field station for two CNR representatives.

Station Operations

Within the constraints of NASA support SAO will, on a best efforts basis:

1. Provide on an operational basis orbital elements in the appropriate format for laser pointing predictions.
2. Provide routine data review and engineering/operations assessment reports on a timely basis.

3. Provide headquarters support in terms of scheduling, priorities, and network coordination.
4. Provide designs for any future hardware upgrades that are applied to the SAO lasers, providing hardware when requested on a cost reimbursement\* basis.
5. Provide any future software modifications and upgrades that are applied to the SAO lasers.
6. Provide repair and maintenance service on a cost reimbursement\* or trade basis as appropriate on hardware, components, systems, and subsystems.
7. Provide Field Engineering support on a cost reimbursement\* basis.
8. Provide reformatted final data from line tape to industry compatible magnetic tape on a routine basis and/or provide the SAO software to perform the reformatting process.

#### CNR RESPONSIBILITIES

##### Station Set Up

CNR will make its best effort to:

1. Provide a building design agreeable to SAO.
2. Prepare the site and building as necessary to accommodate the laser system.
3. Assume all costs for station set up items above.
4. Provide all necessary administrative assistance to SAO personnel entering and leaving Italy.
5. Provide sufficient manpower and local support and resources to set up the station.

##### Station Operations

CNR will make its best efforts to:

1. Operate the station as per the NASA-CNR agreement (specified in a letter from M. G. Finarelli to L. Guerriero dated November 24, 1981).
2. Make all quick-look and final data available to SAO on a punctual basis as agreed.
3. Provide operations and configuration control as per NASA Laser Tracking Network requirements.

\*CNR will reimburse SAO for travel, transportation, local expenses for field personnel, and local purchases of goods and services.

It is intended that this agreement should be in consonance with and subordinate to the NASA-CNR agreement of 29 November 1981 with SAO acting on behalf of NASA.

It is understood that the ability of SAO and CNR to carryout their respective obligations is subject to availability of funds, and in the case of SAO, the concurrence of NASA.

SAO and CNR agree that, with respect to injury or damage to persons involved in operations undertaken pursuant to this agreement, neither SAO nor CNR shall make any claim with respect to injury or death of its own or its contractors' or its subcontractor's employees or damage to its own or its contractors' or its subcontractors' property caused by activities arising out of or connected with this project, whether such injury or damage arises through negligence or otherwise.

This Agreement shall remain in force and effect from the date of its execution for an indefinite period of time, however it may be terminated by either CNR or SAO at any time by giving a one hundred twenty (120) day advance writter notice of termination to the other party.

IN WITNESS HEREOF, the Smithsonian Astrophysical Observatory and the Consiglio Nazionale delle Ricerche have caused this Agreement to be signed and sealed in duplicate.

SMITHSONIAN ASTROPHYSICAL OBSERVATORY

CONSIGLIO NACIONALE DELLE RICERCHE

\_\_\_\_\_  
Signature

\_\_\_\_\_  
Signature

\_\_\_\_\_  
Name and Title

\_\_\_\_\_  
Name and Title

\_\_\_\_\_  
Date

\_\_\_\_\_  
Date